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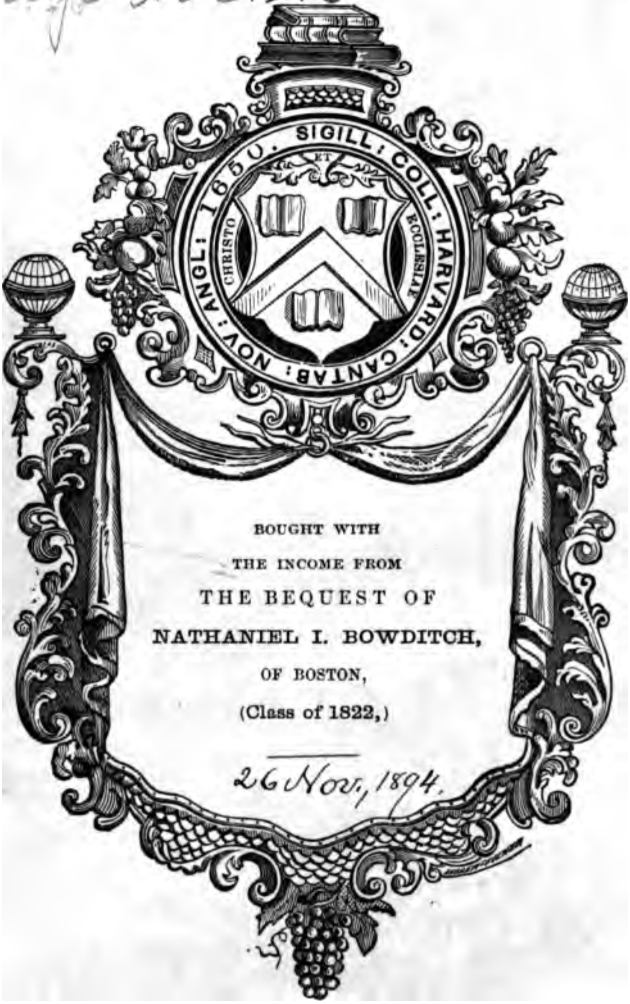
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ELECTRICITY AND MAGNETISM

BEING A SERIES

OF

ADVANCED PRIMERS

OF ELECTRICITY.

BY

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PREFACE.

The "Advanced Primers of Electricity" are in no sense to be regarded as revisions of the author's "Primers of Electricity," which were published during the International Electrical Exhibition held in Philadelphia, in 1884.

The International Electrical Exhibition Primers, written during the early days of the Exhibition, were intended to explain merely the elementary principles of electricity to a public which was then almost entirely ignorant of even the rudiments of the science.

The times, however, have changed since 1884. The public is no longer ignorant of the principles of electrical science. The numerous commercial applications which have been made of this wonder-working force since that time have greatly increased the number of those to whom a knowledge of its laws has become a necessity of every-day business life.

Primers, therefore, based on the simple lines of those of 1884, would now occupy but a comparatively limited field, and the author, in rewriting his Primers, has endeavored to treat the subject more nearly from the standpoint of the present knowledge of the general public.

For convenience the "Advanced Primers" are arranged in three separate books, each complete in itself, viz.: "Electricity and Magnetism, Being a Series of Advanced Primers of Electricity;" "The Measurement of Electric Current, and Other Advanced Primers of Electricity," and "The Electric Telegraph, and Other Advanced Primers of Electricity." Each of these volumes is complete in itself.

In these days of voluminous electrical literature, the student is often in doubt as to the best books with which to begin his studies. As an aid in this direction, and as a species of University Extension Work, there has been placed at the end of each Primer extracts from one or more standard electrical books, so as to give the student some idea of their character, and to enable him to intelligently select the works best suited to his needs.

EDWIN J. HOUSTON.

CENTRAL HIGH SCHOOL,
Philadelphia, Pa.,
October, 1892.

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I.—EFFECTS OF AN ELECTRIC CHARGE.

Probably the first recorded experiment in electricity was that performed by Thales, of Miletus, who noticed that a piece of amber, when rubbed against the clothing, acquired the property of first attracting and then repelling light bodies brought near it. This discovery was made about the year 600 B. C.

By friction against the clothing the amber became electrified, or received an electric charge, and thereby acquired the power of attracting and repelling light objects.

Amber is not the only substance that can be electrified by friction. Indeed, it is doubtful whether any substance exists that cannot be electrified by friction against some other substance, and this is true whether the substances rubbed are solids, liquids, or gases.

For example, a rod of warm, dry glass, briskly rubbed with a dry, silk handkerchief, becomes electrified. If such an electrified rod be held near a light, easily moved object, as, for example, a ball of pith, the ball will be attracted to the rod as shown in Fig. 1. In this apparatus the ball is suspended by a thread attached to a bent wire suitably supported by the glass rod *A*. The wire is so shaped that when the pith ball is acted on by gravity alone it will come to rest in a vertical position at some distance from the support *A*.

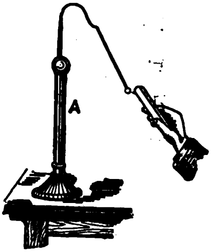

FIG. 1.—ELECTROSTATIC ATTRACTION.

When touched by the electrified glass rod, the pith ball acquires an electric charge and is then immediately repelled as shown in Fig. 2.

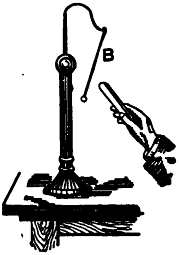

FIG. 2.—ELECTROSTATIC REPULSION.

If the attracting rod is now moved away from the ball, the ball gradually loses its charge, and the ball and its supporting string will assume a vertical position under the influence of the earth's attraction, just as a plumb-line would. As long, however, as the ball retains its charge it will be repelled by the charge possessed by the silk-rubbed glass.

If, however, while the pith ball is charged by the silk-rubbed glass, it be approached by a piece of resin that has been electrified by rubbing with silk, it will be attracted. The kind of electricity produced by rubbing resin with silk is, therefore, different from the kind which is produced by rubbing glass with silk, since it produces different effects.

If experiments be made by rubbing a number of different substances together, it will be found that only two kinds of electricity can be produced, namely, the kind produced by glass when rubbed with silk, and the kind produced by resin when rubbed with silk. We, therefore, correctly infer that there are but two kinds of electricity. These were formerly called vitreous electricity, or electricity like that produced by glass, and resinous electricity, or electricity like that produced by resin.

The terms vitreous and resinous are now universally replaced by the terms positive and negative, since it is well known that the kind of electricity produced by glass, or by resin, depends on the substances with which the glass or the resin is rubbed. For example, glass rubbed by flannel becomes electrified with the same kind of electricity as resin rubbed with silk.

There are, therefore, but two kinds of electricity, namely, positive and negative. A body charged with positive electricity is said to possess a positive charge; a body charged with negative electricity is said to possess a negative charge.

Whenever electricity is produced by friction, the body that is rubbed receives one kind of electricity and the body with which it is rubbed receives another kind. That is to say, if a rod of glass rubbed with a piece of silk becomes positively charged, the silk will at the same time become negatively charged.

In the following table a number of common substances are arranged in such an order that when any two of them are rubbed together, the one which is nearer the top of the list becomes positively excited while the other becomes negatively excited.

1. **Cat's skin.**
2. **Flannel.**
3. **Ivory.**
4. **Rock crystal.**
5. **Glass.**
6. **Cotton.**
7. **Silk.**
8. **The hand.**
9. **Wood.**
10. **Metals.**
11. **Caoutchouc.**
12. **Sealing wax.**
13. **Resin.**
14. **Sulphur.**
15. **Gutta percha.**
16. **Gun cotton.**

(*Ganot.*)

Suppose for example a piece of glass is rubbed with flannel; the flannel will be positively charged since it comes first in the list, while the glass will be negatively charged. If, however, the glass is rubbed with silk, since the glass comes first in the list it will be positively charged, and the silk negatively charged.

A simple experiment in the production of an electric charge by friction can be made as follows: Place a smooth board on a stove and, when thoroughly dried and heated, place on it a sheet of ordinary writing paper, that has also been dried and heated. If, now, the paper be rubbed with a piece of india rubber, it will be found to be strongly electrified, as may be shown as follows:

(1.) If the sheet of paper is brought near one of the walls of a room, it will be attracted and held to the wall with a fairly considerable force.

(2.) If the paper be cut with a penknife into long fringes while on the board, the separated strips of these fringes will, when removed from the board, repel one another in a curious manner.

(3.) If a dry metallic waiter be supported on a dry glass tumbler and the electrified paper be taken from the board and placed on the waiter, a fairly long spark may be drawn from the waiter.

When a body is electrified by friction, or by any other cause, that is, when it has received an electric charge, it acquires the power of producing the following effects, namely:

(1.) It will first attract and afterward repel light objects brought near to it.

(2.) When brought near to a knuckle of the hand or to a blunt metallic object, a faint purplish spark will be seen in the dark.

(3.) The production of the spark is accompanied by a crackling sound.

(4.) If moved near the face, a creeping sensation is experienced, as if cobwebs were being drawn over the skin.

That branch of electric science which treats of electric charges and their effects is called electrostatics.

The laws of electrostatics can be expressed as follows:

(1.) Like charges, that is, charges of like name, repel each other; in other words, a positive charge will repel another positive charge, and a negative charge will repel another negative charge.

(2.) Unlike charges attract each other; that is, a positive charge attracts a negative charge, and, conversely, a negative charge attracts a positive charge.

(3.) The force exerted by either the attraction or the repulsion is directly proportional to the product of the quantities of electricity possessed by the two bodies and inversely proportional to the square of the distance between them.

That like charges repel each other can be proved by the apparatus shown in Fig. 3, in which two pith balls *B B*, hung by silk threads, fly apart and repel each other when charged by the electrified glass rod *S*, brought so as to touch them.

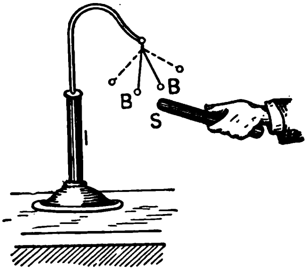

FIG. 3.—PITH BALL ELECTROSCOPE.

Any apparatus which is designed to show the presence of an electric charge is called an electroscope. The pith ball apparatus of Figs. 1, 2 and 3 show forms of simple electroscopes.

A better form of electroscope is shown in Fig. 4, in which two gold leaves, *n*, *n*, are placed parallel to each other and supported by a conducting support inside the glass jar *B*. The conducting supports of the gold leaves terminate outside the jar by the rounded metallic knob or ball *C*. When the gold leaves are charged by bringing an electrified body in contact with *C*, they are repelled.

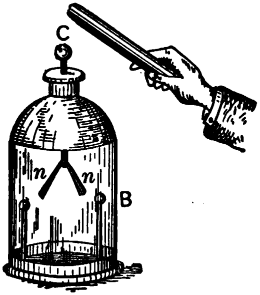

FIG. 4.—GOLD LEAF ELECTROSCOPE.

If the gold leaves are first charged with a weak charge, and the distance they are repelled is observed, it will be noticed that if, on another occasion, they are charged with a stronger charge, the distance they are repelled or driven apart is much greater. The strength of the charge may, therefore, be measured by the distance the leaves are driven apart.

Any apparatus which will permit the accurate measurement of this distance is called an electrometer.

When it is desired to ascertain the kind of charge which a body possesses, that is, whether the charge is positive or negative, the gold leaf electroscope shown in Fig. 4 is used as follows: The leaves are first repelled by imparting to them a small known charge; for example, a positive charge, obtained, say, by touching the knob by a silk-rubbed glass rod. While they are still repelled, the body, the kind of whose charge is to be ascertained, is touched to the knob. If this charge is the same as that of the silk-rubbed glass, namely, positive, the leaves will

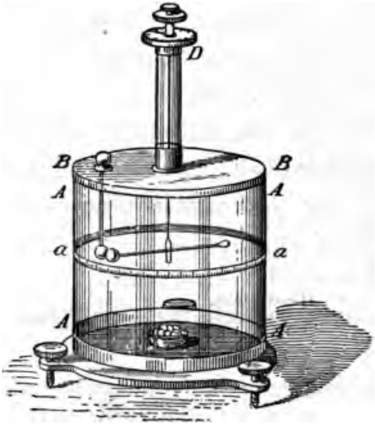

FIG. 5.—TORSION BALANCE.

be repelled still further. If, however, it is negative, the leaves will first be attracted and afterward repelled. In this manner it is easy to determine the character of a charge.

To illustrate the third law of electrostatics, an apparatus called a torsion balance may be used. Its general construction is shown in Fig. 5. A slender needle of shellac is supported by a metallic wire to a movable screw head *D*, provided with a graduated scale. On one end of the shellac needle is placed a gilded ball. Through an opening, *B*, in the top of the glass cage, is inserted an apparatus called a proof plane, consisting of a metallic ball supported on a rod of hard rubber.

To use the apparatus, the proof plane is removed from the glass vessel, touched to the electrified surface whose charge is to be measured and then inserted again in the opening *B*. The ball on the shellac needle is at once attracted, and, receiving an electric charge, is then repelled. The force with which the charge on the proof plane repels the shellac needle is then measured by the angle through which the wire supporting the shellac needle must be twisted in order to move the needle a certain distance toward the proof plane.

It can be shown that an electric charge resides only on the surface of the body charged. If, for example, a hollow metallic sphere be electrified, a proof plane touched to any part of its outer surface receives a charge, but if touched to any part of the inside it receives no charge.

Faraday was in the habit of protecting his delicate electrical instruments from the effects of electric charges by throwing a light gauze covering over them. In Fig. 6 an apparatus called **Faraday's net** is shown, in which a net formed of light gauze or cloth is supported on a glass stand and is provided with silk strings, by means of which it can be readily turned inside out. If the net be electrically charged, the proof plane will not show any charge on the inside of the net, although the outside markedly

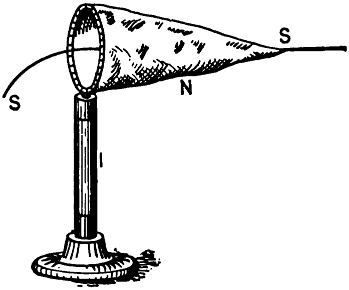

FIG. 6.—FARADAY'S NET.

shows the presence of such a charge. But if the net be turned inside out, the charge will now be found on the outside of the net, and none on the inside. The change in the distribution of the charge takes place practically instantaneously.

Faraday constructed a cubical room twelve feet square, and, therefore, sufficiently large to permit him to go into it with his instruments. The cube was placed in the lecture room of the Royal Institution, of London, and insulated from the same. Although a strong charge was given to the outside walls, which were covered with tinfoil, he could detect no signs of such charge on the inside with his delicate instruments.

EXTRACTS FROM STANDARD WORKS.

Faraday thus describes the experiments with his cubical room in Vol. I. of his "Experimental Researches in Electricity,"* on page 365 :

> I carried these experiments on with air to a very great extent. I had a chamber built, being a cube of twelve feet. A slight cubical wooden frame was constructed, and copper wire passed along and across it in various directions, so as to make the sides a large net-work, and then all was covered in with paper, placed in close connection with the wires, and supplied in every direction with bands of tin foil, that the whole might be brought into good metallic communication, and rendered a free conductor in every part. This chamber was insulated in the lecture-room of the Royal Institution; a glass tube about six feet in length was passed through its side, leaving about four feet within and two feet on the outside, and through this a wire passed from the large electrical machine (290) to the air within. By working the machine, the air in this chamber could be brought into what is considered a highly electrified state (being, in fact, the same state as that of the air of a room in which a powerful machine is in operation), and at the same time the outside of the insulated cube was everywhere strongly charged. But putting the

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* "Experimental Researches in Electricity," by Michael Faraday. London: Bernard Quaritch, 1839. 3 vols., 1464 pages, 245 illustrations. Price, $25.00.

chamber in communication with the perfect discharging train described in a former series (292) and working the machine so as to bring the air within to its utmost degree of charge, if I quickly cut off the connection with the machine, and at the same moment or instantly after insulated the cube, the air within had not the least power to communicate a further charge to it. If any portion of the air was electrified, as glass or other insulators may be charged (1171), it was accompanied by a corresponding opposite action *within* the cube, the whole effect being merely a case of induction. Every attempt to charge air bodily and independently with the least portion of either electricity failed.

I put a delicate gold-leaf electrometer within the cube, and then charged the whole by an *outside* communication, very strongly, for some time together; but neither during the charge or after the discharge did the electrometer or air within show the least signs of electricity. I charged and discharged the whole arrangement in various ways, but in no case could I obtain the least indication of an absolute charge, or of one by induction in which the electricity of one kind had the smallest superiority in quantity over the other. I went into the cube and lived in it, and using lighted candles, electrometers, and all other tests of electrical states, I could not find the least influence upon them, or indication of anything particular given by them, though all the time the outside cube was powerfully charged, and large sparks and brushes were darting off from every part of its outer surface. The conclusion I have come to is that non-conductors, as well as conductors, have never had an absolute and independent charge of one electricity communicated to them, and that to all appearance such a state of matter is impossible.

Silvanus P. Thompson in his "Elementary Lessons in Electricity and Magnetism,"* page 10, remarks as follows concerning the many different substances that will produce electricity by friction:

We will simply remark here that friction between two different substances *always* produces electrical separation, no matter what the substances may be. Symmer observed the production of electricity when a silk stocking was rubbed over a woolen one, though woolen rubbed upon woolen, or silk rubbed upon silk, produces no electrical effect. If, however, a piece of rough glass be rubbed on a piece of smooth glass, electrification is observed; and, indeed, the conditions of the surface play an important part in the production of electricity by friction. In general, of two bodies thus rubbed together, that one becomes negatively electrical whose particles are the more easily removed by friction. Differences of temperature also affect the electrical conditions of bodies, a warm body being usually negative when rubbed on a cold piece of the same substance. Péclet found the degree of electrification produced by rubbing two substances together to be independent of the pressure and the size of the surfaces in contact, but dependent on the materials and the velocity with which they moved over one another. Rolling friction and sliding friction produced equal effects. The quantity of electrification produced is, however, not proportional to the amount of the actual mechanical friction; hence it appears doubtful whether friction is truly the cause of the electrification.

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* "Elementary Lessons in Electricity and Magnetism," by Silvanus P. Thompson. London: Macmillan & Co. 1892. 456 pages, 171 illustrations. Price, $1.25.

In his "Dictionary of Electrical Words, Terms and Phrases,"* page 195, the author remarks as follows concerning the production of electricity by friction:

In the following table the substances are so arranged that any one in the list becomes positively electrified when rubbed by any which follows it:

Positive.

1. Cat's fur.
2. Polished glass.
3. Wool.
4. Cork at ordinary temperatures.
5. Coarse brown paper.
6. Cork heated.
7. White silk.
8. Black silk.
9. Shellac.
10. Rough glass.

Negative. (*Forbes.*)

It will be observed that the character of the charge produced by friction depends on the character of the surfaces rubbed. This is seen from the foregoing table, where—

(1.) The roughness of the surface, as in the case of glass, produces a difference in the nature of the charge; thus, rough glass is at the bottom of the table, and smooth, polished glass near the top.

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* "A Dictionary of Electrical Words, Terms and Phrases," by Edwin J. Houston. Second Edition. New York: The W. J. Johnston Co., Ltd. 1892. 562 pages, 570 illustrations. Price, $5.00.

(2) The state of the surface as shown by the color. Black silk rubbed with white silk is negative to it.

(3.) The state of the surface as varied by the temperature. Hot cork receives a negative charge when rubbed against a piece of cold cork.

Forbes has pointed out that these differences are probably due to the change produced in the ability of the surface to radiate heat or light. A substance or body which radiates the most light or heat is negative. Thus, a hot body radiates more heat than a cold body, and is negative to it. A rough surface is negative to a smooth surface because it radiates more heat than a smooth surface. For the same reason a black surface is negative to a white surface. In this latter case, however, the black surface is the worse radiator of light.

The contact of dissimilar substances has long been considered by some as one of the requisites for the ready production of electricity by friction. In fact, the production of electricity by friction has been ascribed as an effect due to a true contact force at the points of junction of the rubber and the thing rubbed.

Maycock, on page 87 of his "First Book of Electricity and Magnetism,"* describes the method of performing a simple experiment by means of which the effects of an electric charge can be shown.

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* "A First Book of Electricity and Magnetism, for the Use of Elementary Science and Art, and Engineering Students and General Readers," by W. Perren Maycock. London: Whittaker & Co. 1891. 133 pages, 84 illustrations. Price, 60 cents.

Take a well-warmed drawing board, a sheet of hot brown paper and a well-dried clothes brush. Lay the paper on the board and rub it briskly to and fro with the brush. If the paper be then presented with its rubbed side toward the light bodies on the tray (§ 100), or the suspended pith ball, or the suspended wooden lath, electrical attraction will take place, proving that the surface of the paper has been electrified. If the brown paper be presented to the wall of the room, it will cling to it so long as it retains its charge.

Apparatus must be perfectly dry and warm, and free from dust. The electrification produced by friction is at a very much greater potential or pressure than the electrification due to a battery, and for this reason the slightest moisture on the surface of otherwise insulating bodies renders them comparatively good conductors ; consequently these experiments will not succeed unless every care be taken to drive away the moisture by having the apparatus perfectly dry and warm (§ 50). Everything should as well be quite clean and free from dust, for dirt and dust are almost as good conductors of high pressure electricity as moisture.

II.—INSULATORS AND CONDUCTORS.

If a metallic rod be held in the hand and rubbed with a piece of cat's skin or a silk handkerchief, no electric charge can be detected on it. For this reason it was formerly believed that metallic substances could not be electrified by friction. They were, therefore, placed in a class called *non-electrics,* or bodies which could not be electrified by friction, in order to distinguish them from *electrics,* or bodies which could be electrified by friction. This distinction between electrics and non-electrics is no longer made, for the following reason :

If the metallic rod is fastened in a glass handle, and this handle is held in the hand while the rod is rubbed, the metal readily becomes electrified by friction, as can be proved by the use of the gold leaf electroscope shown in Fig. 4. Electricity is produced by friction when the rod is held in the hand, but it rapidly escapes from the rod and passes into the earth through the body of the person holding it. When, however, the metal rod is inserted in a glass handle, or in a handle of any other similar non-conducting substance, and is held by such handle, the charge cannot pass off the rod through the glass, and therefore remains on the rod.

Substances differ as regards the ease with which electricity flows through them. Some will allow the electricity to pass through them quite readily; others will not allow electricity to so pass without difficulty.

Substances which permit electricity to flow through them are called conductors. Substances which will not permit electricity to readily pass through them are called non-conductors.

The difference between conducting and non-conducting substances may be shown by means of the following experiment: Stretch a metallic wire and a silk thread parallel to, but some distance from one another, between two walls of a room, by attaching the ends to hooks. In the case of the wire fasten a silk thread to each end of the wire and attach it to the hooks by such silk ends. If, now, an assistant holds a gold leaf electroscope or a pith ball electroscope so as to touch one end of the wire, it will immediately show the presence of an electric charge when an electrified body, such, for example, as a silk-rubbed glass rod, is held so as to touch the other end. Here the charge passes from the glass rod through the entire length of the wire, and charges the gold leaves of the electroscope, or the pith balls.

In other words, the wire acts as a conductor of electricity.

If, however, the electrified body is held to one end of the silk cord, no effect is produced at the other end, on either the pith balls or the gold leaf electroscope. In other words, the silk cord will not conduct electricity.

In the following table the substances are arranged in the order of their conducting powers for electricity. Those at the top of the list are good conductors of electricity, while those at the bottom of the list are poor conductors.

Table of Electrical Conducting Powers.

1. Silver.
2. Copper.
3. Metals generally.
4. Well burned charcoal.
5. Graphite.
6. Acids.
7. Saline solutions.
8. Water.
9. Snow.
10. Vegetables (living).
11. Animals (living).
12. Moist earth.
13. Linen.
14. Cotton.
15. Alcohol.
16. Powdered glass.
17. Flowers of sulphur.
18. Baked wood.
19. Paper.
20. Oils.
21. Porcelain.
22. Air and dry gases.
23. Silk.
24. Diamond.
25. Glass.
26. Wax.
27. Sulphur.
28. Resins.
29. Amber.
30. Gutta percha.
31. Shellac.
32. Ebonite, or vulcanite.

An inspection of this table shows that silver, copper and the metals generally are the best conductors of electricity, while ebonite, shellac and gutta percha are the worst conductors. As the table is arranged we may regard it as a table of electrical conductivity, the substances placed near the end of the list being those which possess the least conductivity. If, however, the table be read from the bottom upward, it will then be a table of non-conductors, the poorest non-conductors then coming near the top of the table.

A conductor supported by or resting on a non-conductor, is said to be *insulated*. When in this condition, it can receive and retain an electric charge. As non-conductors will thus insulate a body, they are often called insulators.

Since a non-conductor opposes the passage of electricity through it, or offers a resistance to such passage, it is said to possess an electric resistance. Even the best conductors offer some resistance to the passage of electricity through them.

The higher the conducting power of a substance, the lower its electrical resistance. Conversely, the lower the conducting power, the higher its electrical resistance. In other words, the conducting power is equal to the reciprocal of the resistance.

An electric charge resides on the surface of a conductor. A steady electric discharge passes through the mass of the conductor. Therefore, when the discharge is great, the conductor must be made large, that is, of great area of cross section. The higher the conducting power, however, the smaller the area of cross section necessary to safely carry a given steady discharge. In the case of electric discharges the direction or intensity of which varies suddenly, the above statements need modifications which will be considered in another Primer.

The conducting power of a substance for electricity varies in a marked manner with its physical condition. The conducting power of most metals decreases with an increase of temperature; carbon, however, forms an exception to this rule. Glass, which is a poor conductor when cold, conducts electricity when fused. Wrobleski has shown that at very low temperatures the conducting power of the metals increases.

A very small percentage of impurities greatly decreases the conducting power of copper. A very small quantity of carbon, zinc, or iron lowers the conducting power of copper one-half.

As a rule alloys are poorer conductors of electricity than the metals from which they are made. Some alloys, however, possess the valuable property of being but slightly affected as regards their conducting power by changes of temperature.

Among the metals, copper and iron are the most frequently used in the commercial applications of electricity, owing both to their cheapness and their excellent conducting powers.

Insulators are used either to prevent an electric charge from escaping from a body, or to insure the passage of electricity from one point of a body to another without an escape occurring at any intermediate points.

In the case of apparatus in which it is desired to maintain an electric charge, the charged body may be insulated by being supported on glass rods or pillars coated with shellac varnish, in order to prevent the ready deposition of moisture, which greatly increases the conducting power of the glass. Supports of hard rubber or vulcanite are also frequently used for the same purposes.

In case the wires or other conductors, through which it is desired to pass electricity, do not pass through the air or other non-conductor, the entire surfaces of the conductors must be covered or coated with a layer of some good insulating material.

This kind of insulation is generally obtained by wrapping or braiding cotton or silk over the wire. This covering is either used alone, or is afterward coated with wax, paraffine, shellac, or other good insulating substance applied hot, or in a liquid state, and afterward hardened.

In the case of wires or conductors that are designed for use under water, the insulating material must possess high non-conducting powers. It must, moreover, be impervious, and great care is necessary in order to prevent the water from penetrating and thus injuring the insulation. When used for such purposes, several single wires or conductors are generally placed together in what is called a cable. Gutta percha forms one of the best known insulating substances for cables, since it is not injuriously affected by salt water, and is quite impervious under pressure.

A submarine cable is one designed for use under the sea. Such a cable consists of a conducting wire or wires called the core, the separate wires of which are insulated from one another, and from the surrounding water, and covered by a number of strands of tarred hemp or jute, wrapped around the insulating core of the cable, in order to protect it from the pressure of a metallic armor consisting of strands of iron wire or other metallic covering, such as a coat of lead.

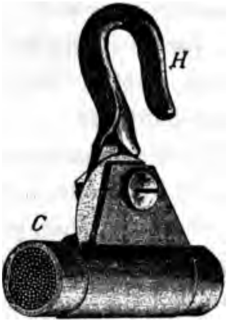

FIG. 7.—OVERHEAD OR AERIAL CABLE.

In Fig. 7 is shown a form of overhead or aerial cable. It is hung from steel wires strung on poles. The cable is designed for telegraph or telephone wires or conductors. It consists of a number of separate wires or conductors insulated from one another, the whole cable being covered with lead.

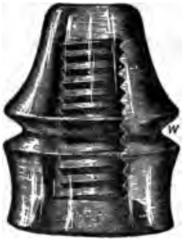

FIG. 8.—GLASS INSULATOR.

Overhead wires or conductors for telegraph or telephone service are generally bare or uninsulated; they, therefore, require to be insulated from the poles on which they are hung. This is accomplished by the use of what are technically known as insulators. Insulators are of a variety of forms.

A well known form of glass insulator is shown in Fig. 8. The conductor is passed around the central groove of the insulator, and securely fastened thereto by a binding wire. The insulator is connected to the cross arm of the telegraph pole by being secured by a wooden pin and fastened thereon by a screw thread formed in the glass of the insulator.

Two other forms of insulators are shown in Figs. 9 and 10, formed respectively of porcelain and of hard rubber.

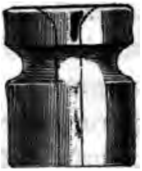

FIG. 9.—PORCELAIN INSULATOR.

Two things should be considered in the construction of an insulator, namely:

(1.) The insulating power of the material of which the insulator is composed. A material of high insulating power should be selected, so as to reduce the leakage as far as possible.

(2.) The tensile strength of the material should be high, so as to avoid the liability of breaking under strain caused by heavy wires.

The electricity which passes off or leaks from a line wire or conductor through an insulator must escape from the wire over the insulator, to the pin to which the insulator is attached, and thence to the cross arm, pole and ground.

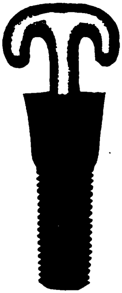

FIG. 10.—HARD RUBBER INSULATOR.

As the insulating power is decreased by the collection of dust on the surface of the insulator, the insulators should be placed where they are exposed to the cleansing action of the rain.

Where a very high insulation is desired, a fluid insulator is used, provided with an internally placed groove, or cup-shaped space filled with oil. Here any surface leakage, between the wire and the ground, can only occur by the current passing or crossing the oil in the cup.

In telegraph or telephone lines, where one line is to be joined to another, care must be taken in order to avoid a marked decrease in the conducting power at the joint.

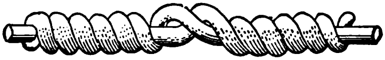

FIG. 11.—AMERICAN TWIST JOINT.

A form of joint much used in the United States, called the American twist joint, is shown in Fig. 11. Here the two wires are twisted about one another as shown and sometimes the joint is afterward soldered.

The form of joint shown in Fig. 12 is called the Britannia joint. Here the wires are laid side by side, bound together, and subsequently soldered.

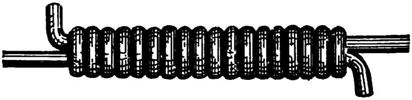

FIG. 12.—BRITANNIA JOINT.

In the case of the conductors used in arc lighting, or for the general electrical distribution of power, the wires are generally insulated by covering them with cotton and subsequently painting to exclude moisture.

In the case of wires or conductors used in electric railways, since the electricity is taken from the conductors by means of traveling wheels called trolleys, or by moving or sliding contacts called plows or sleds, the wires are necessarily left bare and uninsulated. Great care is, therefore, necessary in order to insure good insulation where the conductors are supported by the poles.

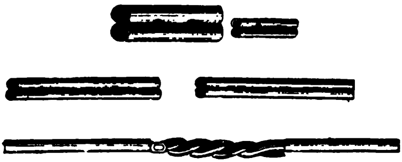

FIG. 13.—MCINTIRE'S PARALLEL SLEEVE JOINT.

An excellent form of joint, that is rapidly coming into extended use, is known as McIntire's parallel sleeve joint. As its name indicates, the ends of the wires that are to be joined are slipped into parallel sleeves or tubes, which are afterward twisted around each other.

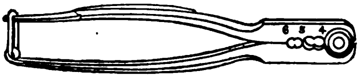

FIG. 14.—TWISTING CLAMP FOR McINTIRE'S PARALLEL SLEEVE JOINT.

A general view of the parallel sleeve joint, both before and after twisting, is shown in Fig. 13.

The twisting is done by means of the specially devised twisting clamp shown in Fig. 14.

EXTRACTS FROM STANDARD WORKS.

Pope, in the revised edition of his "Modern Practice of the Electric Telegraph,"* in considering the subject of conductors and insulators, says on page 56:

Although all bodies offer more or less resistance to the passage of the electric current, there is an enormous difference in the resisting capacity of different substances. Those which offer comparatively little resistance are called in a general sense *conductors* of electricity, while those that offer great resistance are termed *insulators*. This distinction, like that, for example, between heat and cold, is wholly relative and not absolute. The most perfect known conductors offer some resistance to the current, and the most perfect insulator known permits some current to pass. But the actual difference in some substances is almost beyond the power of the mind to grasp.

"It is difficult to find any comparison which will give a tolerably good idea of the extraordinary difference between the electrical resistance of these two materials (copper and gutta-percha). It is about as great as the difference between the velocity of light and that of a body moving through one foot in 6,700 years; yet the measurement of the two quantities is daily made by the same apparatus and the same standards of comparison. This fact is well calculated to give an idea of the range of electrical measurements, and the perfection to which the instruments employed have been brought."*

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* "Modern Practice of the Electric Telegraph. A Technical Handbook for Electricians, Managers and Operators," by Franklin Leonard Pope. Fourteenth Edition. New York: D. Van Nostrand Company. 1891. 234 pages, 185 illustrations. Price, $1.50.

The division of bodies into two classes of conductors and insulators, though in a certain sense arbitrary, is very convenient in practice. In telegraphy the term conductor is applied to all substances which are used in any manner as a portion of the conducting circuit, while, on the other hand, the term insulator is applied to all substances which are employed to confine the electrical current to such conductors by preventing its escape in undesired directions. Following is a list of some of the substances so used, arranged as nearly as possible in the order of their specific conductivity:

CONDUCTORS.

1. Copper.
2. Zinc.
3. Platinum.
4. Iron.
5. Nickel.
6. Tin.
7. Lead.
8. Mercury.
9. Carbon.
10. Acids.
11. Aqueous solutions and metallic salts.
12. Water.
13. Wood, moist.
14. Earth, moist.

INSULATORS.

15. Metallic oxides.
16. Ice, dry.
17. Paper, dry.
18. Wood, dry.
19. Earth, dry.
20. Cotton.
21. Glazed porcelain.
22. Silk.
23. Bitumen.
24. Sulphur.
25. Oxidized oils.
26. Balata.
27. India rubber.
28. Gutta-percha.
29. Shellac.
30. Paraffine.
31. Hard rubber.
32. Glass.
33. Air.

The conducting power of all alloys or mixtures of different metals is very much less than that of any one of the metals of which they are composed. The air is the most perfect non-conductor known, even when charged to saturation with aqueous vapor, but it should be remarked that when the moisture of such vapor is deposited upon the surface of insulating supports it may form a conducting film of water.

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*Fleeming Jenkin on Submarine Telegraphy in *North British Review*, December, 1866.

III.—EFFECTS OF AN ELECTRIC DISCHARGE.

When an electrified body is so placed that its charge can be transferred to the earth, or to another body, it loses its charge, or is discharged.

This discharge may be effected in a variety of ways:

(1.) By connecting the charged body by means of a conductor with the body that is to receive its charge.

In such cases the discharge takes place quietly. This kind of a discharge is called a *conductive discharge.*

(2.) By bringing a rounded or blunted earth-connected body near to the charged body, but not actually touching it.

Under these circumstances the discharge takes place suddenly by jumping across the air space between the charged body and the body that is to be charged. This kind of discharge is called a *disruptive discharge.* When it occurs, the air between the two bodies is suddenly pierced by the discharge. The lightning flash is an example of a disruptive discharge. A disruptive discharge, as will be afterward shown, is oscillatory in character; that is, the discharge is not completed by a single out-rush, but is attended by many out- and in-rushes which produce true electric oscillations.

(3.) By placing a pointed conductor in electrical connection with the charged body, or by holding a pointed conductor near it.

A charged body, even though supported on a good insulating substance, will quietly part with its charge if any part of its surface is furnished with sharp points or projections.

The cause of this discharge is as follows: The charge on the surface of the body is greatest in the neighborhood of the points. The air particles, which come in contact with the charged body near the points, receive minute charges, and are then repelled from the points, thus gradually discharging the body. A discharge of this character is called a *convective discharge.*

When an electric discharge occurs, that is, when electricity passes through a conductor, a number of effects are thereby produced either in the conductor itself or in the space or region surrounding it. These effects can be arranged under the following heads:

(1.) Mechanical effects.
(2.) Thermal or heating effects.
(3.) Luminous effects.
(4.) Magnetic effects.
(5.) Chemical effects.
(6.) Physiological effects.

MECHANICAL EFFECTS.

The mechanical effects of an electric discharge are best seen in the case of the powerful discharges that occur in lightning flashes. The passage of such discharges is attended by the rupture or breaking of any substances that are placed in their path. Such effects are seen in the splitting of large trees, the shattering or tearing of walls, and the destruction of structures generally.

If a piece of cardboard is placed in the path of a sufficiently powerful discharge, the discharge will pass through and pierce it. An examination of the hole so made shows raised edges or burrs on both sides of the card. If the discharge passed through the card from one face to the other, there should be, it might seem, a depression where it entered the card, and an elevation where it left it. In reality, however, a raised burr or projection exists on both faces of the card, just as if the discharge had started at the middle of the card and proceeded simultaneously in opposite directions. A possible explanation of this phenomenon is that the discharge causes within the mass of the card a minute explosion, due to the volatilization of a portion of its material. The discharge, therefore, probably does enter the card at one face and pass out at the other.

Another illustration of the mechanical effects of an electric discharge is seen in some of the phenomena of the convective discharge.

During a convective discharge electrified air particles pass off from the points. If, as in Fig. 15, a pointed wire *P* be connected to a charged body, as, for example, one of the conductors of a frictional electrical machine, on the charging of the machine by turning the handle, air particles are thrown from *P* in a steady stream, thus producing an electrical

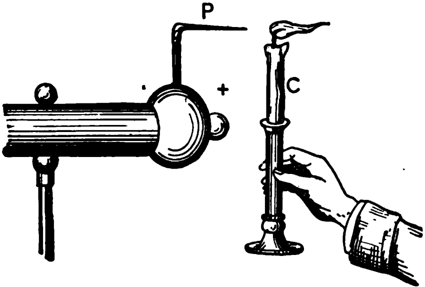

FIG. 15.—THE ELECTRIC BLOW-PIPE.

breeze or wind. This apparatus is sometimes called the electric blow-pipe. The existence of this breeze can be proved by bringing a lighted candle *C*, near to the point *P*, when the flame is blown aside in the manner shown in the figure.

The air particles that form a convective stream produce a reaction on leaving the point, just as a stream of water or other fluid does when it escapes from an orifice in a containing vessel. In the apparatus called the electric flier, a metallic wheel formed of radial arms, bent as shown in Fig. 16, placed so as to be capable of rotation on the vertical axis *A*, and supported on the conductor of an electrical machine, is set into rapid rotation by the reaction of the electrified air particles which escape from the points.

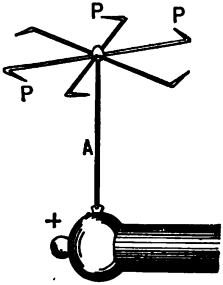

FIG. 16.—THE ELECTRIC FLIER.

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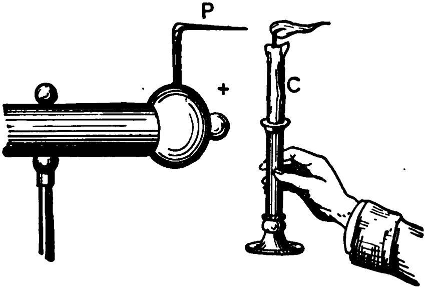

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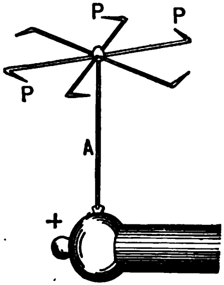

FIG. 16.—THE ELECTRIC FLIER.

THERMAL OR HEATING EFFECTS.

When an electric discharge passes through a conductor, it produces an increase of temperature in the conductor. The amount of heat produced varies both with the quantity of the discharge and the resistance which the conductor offers to the passage of electricity through it.

The heating power of an electric discharge can be shown by means of an apparatus called an electric calorimeter. This apparatus as shown in Fig. 17, consists essentially of a coil of wire, immersed in a liquid placed in a suitable containing vessel. As the discharge passes, the temperature of the liquid rises, as is shown by the thermometer *T*, inserted in the liquid.

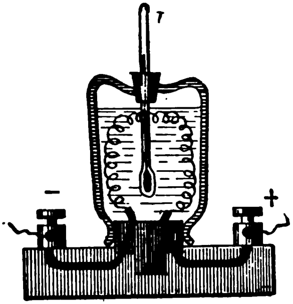

Fig. 17.—The Electric Calorimeter.

Some heating effect is produced, no matter what may be the resistance of the conductor, or how feeble the electric discharge that passes through it. As a rule, however, the higher the resistance of the conductor, the smaller its dimensions, and the stronger the discharge passing through it, the more pronounced are the heating effects produced. In electric welding, and in the case of an extended class of apparatus called electric heaters, the heating effects of the discharge are utilized.

LUMINOUS EFFECTS.

When the heating of an electric conductor is carried to a sufficiently high point, the conductor is rendered incandescent, and gives off light as well as heat.

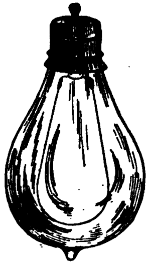

FIG. 18.—INCANDESCENT ELECTRIC LAMP.

An illustration of this is seen in the case of the electric incandescent lamp, where a slender filament of carbon is heated to luminosity by the passage of a sufficiently powerful discharge. In order to prevent the heated carbon from being rapidly consumed by the air, it is placed inside a glass vessel from which all the air has been exhausted. The well-known form given to the incandescent lamp is shown in Fig. 18.

If a sufficiently powerful discharge is passed between two pieces of hard carbon, by first bringing them into contact, and then slowly separating them, a brilliant arc of flame, called the voltaic arc, is produced. This arc is employed as a source of light in the electric arc lamp. As the discharge passes, a minute crater is formed in the piece of carbon from which the discharge comes, and a tiny projection or

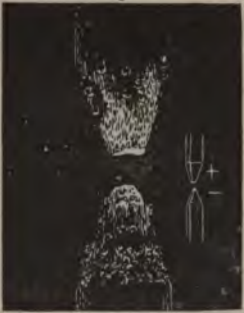

FIG. 19.—THE VOLTAIC ARC.

nipple is simultaneously formed on the other carbon where the discharge enters.

The crater is due to the volatilization of the carbon by the intense heat, and the projection, to the deposition of cooled carbon vapor.

The appearance presented by the carbons after the discharge has been going on for some time is shown in Fig. 19. The upper carbon is here represented as the one from which the discharge passes; the lower carbon as that into which it enters. The formation of the crater and its opposing nipple can be seen by an inspection of the drawing.

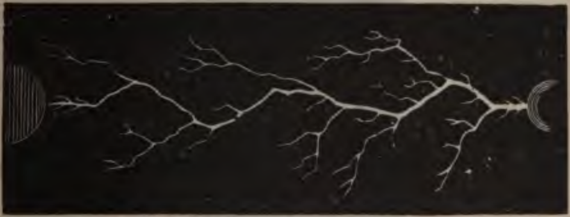

FIG. 20.—A DISRUPTIVE DISCHARGE.

A great variety of other luminous effects are produced by the passage of a disruptive discharge through air or other gases. For example, a disruptive discharge, when passed through air, will, when sufficiently powerful, assume the curious branched form shown in Fig. 20, which in many respects resembles the irregular course or path taken by a lightning flash.

Curious luminous effects are produced by the passage of a discharge through partial vacua. If the air in the egg-shaped glass vessel shown in Fig. 21 is

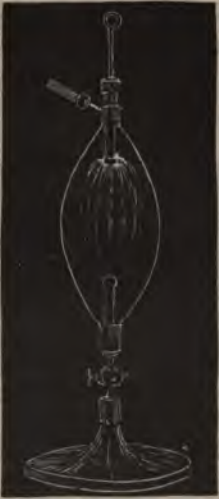

FIG. 21.—A DISCHARGE IN A VACUUM.

partially removed, and a discharge is passed between the metallic terminals at the top and bottom of the vessel, instead of taking the irregular path shown in Fig. 20, it forms an ovoidal mass of faint, bluish light of great beauty.

The color of the spark varies in different gases.

When the exhausted vessel contains traces of air, the color of the spark is bluish ; when it contains traces of hydrogen, the color is crimson; with carbonic acid or chlorine, it is greenish.

MAGNETIC EFFECTS.

The passage of a discharge through a conductor endows the conductor with magnetic properties. While the discharge is passing, the conductor will, therefore, attract iron filings to it, or repel an easily moved magnetic needle. The conductor loses this property as soon as the discharge ceases to pass.

This curious property acquired by a conductor through which a discharge is passing was first noticed by Oersted. It can be shown by holding a wire, through which a discharge is passing, above and parallel to a magnetic needle, as shown in Fig. 22. The needle will tend to set itself at right angles to the wire, and, if the discharge is suffi-

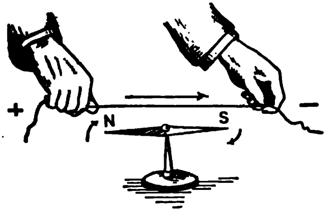

FIG. 22.—OERSTED'S EXPERIMENT.

ciently strong, will come to rest at right angles to it.

The fact that a conductor through which a discharge is passing thereby acquires magnetic properties is utilized in the production of the electro-magnet, a piece of apparatus of very great value in numerous practical applications in electric science.

CHEMICAL EFFECTS.

The passage of an electric discharge under certain conditions through compound substances results in their chemical decomposition.

Chemical decomposition effected by an electric discharge is called electrolysis. The chemical effects of the discharge are utilized in the different applications of electro-metallurgy. By means of various electro-metallurgical processes, conducting surfaces can be covered with an adherent, coherent layer of metal, or casts or molds in metal can be obtained of any object, the surfaces of which can be rendered electrically conducting. These processes are called respectively electroplating and electrotyping.

PHYSIOLOGICAL EFFECTS.

The passage of an electric discharge through the human body produces effects that vary from an agreeable tingling sensation to convulsive contractions of the muscles, and may even result in practically instantaneous death.

In 1786, Luigi Galvani created great excitement throughout the scientific world by showing that when the muscles of the legs of a recently killed frog were connected by means of two dissimilar metals with a nerve, convulsive movements of the legs were thereby produced.

Galvani thought he had discovered the vital fluid or animal electricity, and that this fluid, by flowing from the nerve, passing through the conducting metal and falling on the muscles, caused their convulsive twitchings. Volta showed that the cause of these movements is the passage of an electric discharge through the nerves and muscles.

At first, Volta accepted the explanation which Galvani gave of the phenomenon, but a very extended series of experiments led him to the conclusion above referred to; viz., that what Galvani had actually discovered was neither the source of vitality nor the presence of animal electricity, but a new method of producing electricity.

Volta carried on his investigations with great skill and perseverance, and finally gave to the world that most wonderful invention, the voltaic cell. By this invention Volta placed at the disposal of scientific men a simple though powerful method of obtaining electricity.

The construction and operation of the voltaic cell will be explained in a subsequent Primer.

That branch of electric science which treats of the electric conditions of living animals and plants is called electro-biology.

Electro-biology can be conveniently divided into two branches, viz.:

(1.) Electro-physiology, or the study of the electric phenomena of living animals and plants; and,

(2.) Electro-therapeutics, or the applications of electricity to the curing of disease.

Considerable attention has recently been given to the physiological effects of electricity on the human body, and the number of successful applications of electro-therapeutics is rapidly increasing. Great care, however, should be exercised in the use of this powerful therapeutic agency. Improperly applied, it may do more harm than good. Its application should therefore be strictly limited to the skilled physician.

EXTRACTS FROM STANDARD WORKS.

In the second edition of his "Dictionary of Electrical Words, Terms and Phrases,"* the author describes, under the title, "Discharge, Luminous Effects of," on p. 169, some of the luminous effects of an electric-discharge.

DISCHARGE, LUMINOUS EFFECTS OF.—The luminous phenomena attending and producing an electric discharge.

The luminous effects vary as to color, intensity, shape and accompanying acoustic phenomena according to a variety of circumstances, the principal of which are as follows, viz.:

(1.) With the kind of gaseous medium through which the discharge passes. Thus, a spark passed through hydrogen has a crimson or reddish color, through carbonic acid or chlorine, a greenish color.

(2.) With the density of the medium. In a partial vacuum, the discharge from an induction coil becomes an ovoidal mass of light. As the vacuum increases, the light at first grows brighter, but as a higher vacuum is reached striæ of alternate dark and light bands appear. Finally, with very high vacua the discharge fails to pass.

(3.) With the nature of the substances forming the points from which the discharge is taken. This is due to the partial volatilization of the material of the electrodes.

(4.) With the kind of electricity, *i. e.*, whether positive or negative. A positive charge assumes the shape of a fan; a negative discharge, that of a star.

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* "A Dictionary of Electrical Words, Terms and Phrases," by Edwin J. Houston. Second Edition. New York: The W. J. Johnston Co., Ltd. 1892. 562 pages, 570 illustrations. Price, $5.00.

(5.) On the density of the discharge. The introduction of a Leyden jar or condenser in the circuit of a Holtz machine, for example, causes the spark to change from a faint bluish to a silvery white.

(6.) The disruptive discharge through air is attended by a snapping or crackling sound, which, in the case of lightning, reaches the intensity of thunder. When the disruptive discharge takes place through a vacuum, a faint hissing sound is heard, or all sound may entirely disappear.

(7.) Luminous effects resulting from molecular bombardment occurring in comparatively high vacua. These luminous effects may result:

(a.) From actual incandescence of some refractory material produced by the blows of the molecules; or,

(b.) As a result of phosphorescence or fluorescence due to such blows.

Canary glass, or glass stained by uranium oxide, fluoresces and emits a yellowish green light; solution of sulphate of quinine emits a bluish light.

Concerning the physiological effects of the electric discharge, W. H. Preece, in the revised edition of the "Student's Text-Book of Electricity," by Noad,* on page 67, remarks:

The sensation experienced when the body is made part of an electric circuit through which a Leyden phial is discharged is too universally known to need description.

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* "The Student's Text-Book of Electricity," by Henry M. Noad. Revised by W. H. Preece. London: Crosby, Lockwood & Co. 1879. 615 pages, 471 illustrations. Price, $4.00.

A small charge determined down the spine generally causes a person to fall to the ground; the discharge of a powerful battery in the same direction would probably prove fatal.

Animals the most tenacious of life are destroyed by energetic shocks passed through them. Van Marum found that eels are instantly killed when moderate shocks are sent through their bodies. It was first shown by Dr. Watson, soon after the discovery of the Leyden phial, that the shock may be transmitted through the bodies of several men touching each other. For this purpose, all must join hands, the first touching the outside of the phial, and the last the knob; those in the center will receive a less violent shock than those near the two extremities of the chain, a phenomenon which favors the hypothesis of two fluids. Dr. Watson in 1747 conveyed the electric shock across the Thames at Westminster Bridge, and a few days after he caused it to make a circuit of two miles at the New River at Stoke Newington. The Abbé Nollet communicated a shock to an entire regiment of 1,300 men; and at the convent of Carthusians the shock from the discharge of a large Leyden jar was felt by every individual in a circuit which comprised 5,400 feet.

The bodies of animals killed by a powerful shock of electricity are found to undergo rapid putrefaction, and it is a remarkable fact that after death the blood does not coagulate.

When the Leyden phial was first discovered, it was imagined that an agent of almost unlimited medica power was raised, and it was applied indiscriminately for the cure of the most opposite diseases. The failures consequent on such quackery brought electricity into disrepute, and for a long time its use was almost discarded. It is now more generally employed, and has been found of service in many cases, such as palsy, contraction of the limbs, rheumatism, St. Vitus' dance, some kinds of deafness and impaired vision.

IV.—ELECTRIC SOURCES.

It is a mistake to suppose that it is difficult to produce electricity. In point of fact, electricity is constantly being produced during the phenomena of everyday life, and its presence would manifest itself were it not so readily dissipated. In other words, there are many ways of producing electricity besides the friction or rubbing of one substance against another.

Among the most important of these ways may be mentioned chemical action, differences of temperature, the motion of conductors past magnets, and the various physical and chemical processes that occur during the life and growth of plants and animals.

It was formerly believed that electricity produced by any one of these different ways differed from that produced by any other way. It is now known, however, that no matter how electricity is produced, it is one and the same thing.

Although the oneness of electricity, however produced, is now thoroughly recognized, yet it is found convenient, in practice, to employ the old terms, which characterize the kind of electricity by the source from which it is obtained. Although these terms no longer possess the significance formerly given to them as representing different kinds of electric force, yet they are still generally employed.

These names are as follows:

(1.) Frictional Electricity, or that produced by the friction of one substance against another.

(2.) Voltaic Electricity, or that produced by the contact of two dissimilar substances under the influence of chemical action.

(3.) Thermo-Electricity, or that produced by differences of temperature at the junction of two dissimilar metals.

(4.) Pyro-Electricity, or that produced by differences of temperature in certain crystalline solids.

(5.) Photo-Electricity, or that produced by the action of light.

(6.) Magneto-Electricity, or that produced by the motion of conductors past the poles of permanent magnets.

This is a variety of,

(7.) Dynamo-Electricity, or that produced by the motion of conductors past electromagnets; and,

(8.) Vital Electricity, or that produced under the influence of life, or accompanying life.

Any contrivance or arrangement of parts by means of which electricity can be produced is called an electric source.

Although the exact nature of electricity is unknown, yet in all cases energy must be expended in order to produce it ; and, moreover, the expenditure of a certain amount or quantity of energy should produce a definite quantity or amount of the thing called electricity.

Electric sources can be conveniently arranged in groups or classes, according to the character of the energy which has been expended in producing the electricity, or according to the manner in which such energy acts. The following classification of electric sources is based on this :

	Name of Source.	*Kind of Energy.*
Electric sources.	(1) Frictional electric machine.	Mechanical energy or energy of mass motion.
	(2) Hydro-electric machine.	
	(3) Magneto-electric machine.	
	(4) Dynamo-electric machine.	
	(5) Voltaic cell.	Chemical potential energy.
	(6) Charged storage cell.	
	(7) Thermo-electric cell.	Radiant energy.
	(8) Crystal of tourmaline.	
	(9) Vital electricity.	Vital energy.

When it is desired to obtain electricity by friction in a more constant manner than by the mere rubbing of one substance against another, some form of frictional electrical machine is employed. A well-known form of such machine is shown in Fig. 23. Here electricity is produced by the friction of a glass plate *A*, against a rubber *B*, covered with some kind of cloth, over the surface of which an amalgam of mercury and tin has been spread. The electricity produced on the plate, by the friction of the glass against the rubber, is carried off from the plate to the insulated conductor *D*, by means of a comb furnished with metallic points placed in electrical connection with the conductor *D*. In this way the conductor *D*, receives a positive charge,

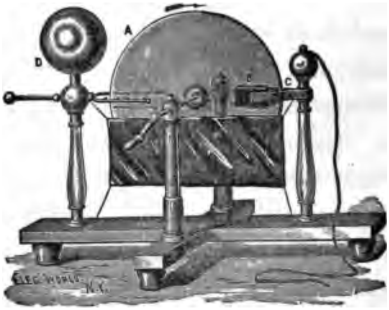

FIG. 23.—FRICTIONAL ELECTRIC MACHINE.

while, at the same time, a smaller metallic conductor *C*, connected with the rubber, receives a negative charge.

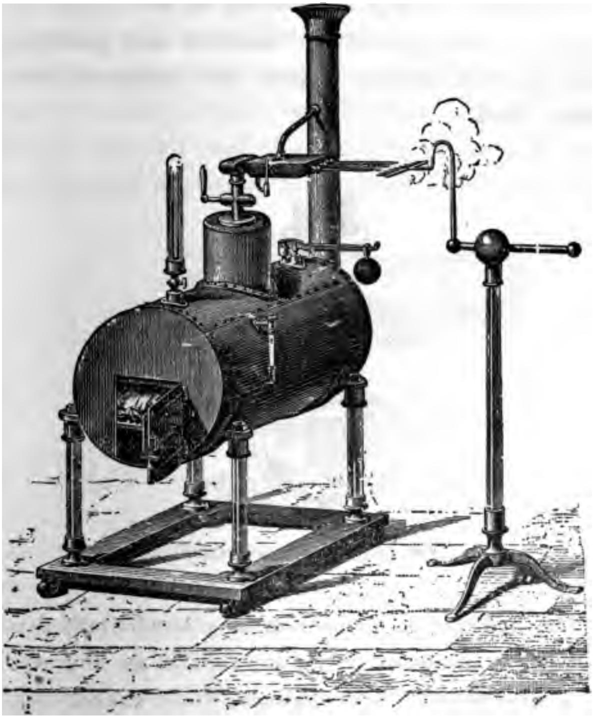

FIG. 24.—ARMSTRONG'S HYDRO-ELECTRIC MACHINE.

A variety of frictional electrical machine in which the charge is produced by the friction of

drops of water against one another is shown in Fig. 24. This form of machine is known as Armstrong's hydro-electric machine.

The electric charge is produced by the friction of drops of water against one another, and, possibly, also by their friction against the surface of the water itself.

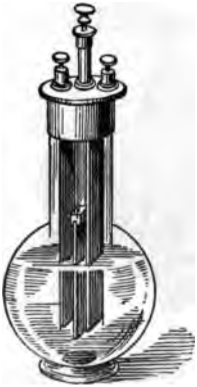

FIG. 25.—THE GRENÈT CELL.

The hydro-electric machine was accidentally discovered by means of a shock given to an engineer of a locomotive. The engineer, while endeavoring to mend a leaky boiler, placed his hand in the escaping steam and received an electric shock. The manner of the production of this electricity was studied by Sir William Armstrong, who afterward devised the apparatus shown in the figure.

The voltaic cell forms an exceedingly important source of electricity. In this variety of source the electricity is produced by chemical action.

A well-known form of such an electric source, the bichromate or Grenèt cell, is shown in Fig. 25. The Grenèt cell consists essentially of two plates of carbon with a plate of zinc placed between them. The plates are dipped in an acid liquid that attacks or dissolves the zinc plate. Electricity is produced as a result of the chemical action thus set up. This form of electric source is called a voltaic cell after Alexander Volta, who first showed how electricity could be produced by chemical action.

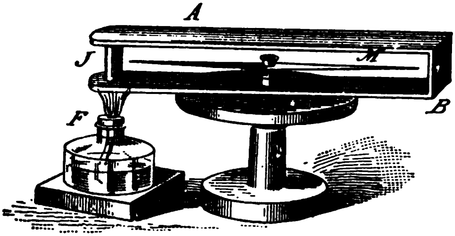

FIG. 26.—PRODUCTION OF THERMO-ELECTRICITY.

Electricity produced by chemical action is generally called voltaic electricity.

Electric charges can be produced by differences of temperature. If a short cylinder of bismuth, *J*, be placed as shown in Fig. 26, in a gap in the hollow rectangle of copper *A B*, and the rectangle be unequally heated, as by the flame *F*, of an alcohol lamp placed as shown, a constant electric discharge will pass through the metallic path provided by the rectangle, and the magnetic needle *M*, will be deflected by such discharge.

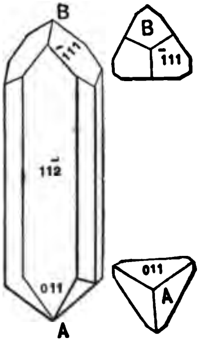

Fig. 27.—Production of Pyro-Electricity.

Here electricity is produced by differences of temperature. If all parts of the rectangle were equally heated, no electricity would be produced.

Electricity produced in this manner by differences of temperature is called thermo-electricity.

When certain crystalline bodies are unequally heated, electricity is produced as long as they remain unequally heated.

If, for example, a crystal of a mineral called tourmaline be unequally heated, one end of the crystal will, while the temperature is rising, acquire a positive charge, and the other end a negative charge. While the temperature of the crystal is falling, opposite charges are produced. Such a crystal is shown in Fig. 27. The end *A*, which acquires a positive electrification while the temperature of the crystal is rising, is called the analogous pole. The opposite end *B*, is called the antilogous pole.

A heated tourmaline crystal, if suspended by a silk fibre, will be attracted or repelled by a second heated tourmaline, like any other charged body.

Electricity produced in this way, in crystalline bodies, by differences of temperature is called pyro-electricity.

At the present time nearly all the powerful electric discharges required for the production of electric light or power are obtained by the motion of conductors past the poles of permanent or electromagnets.

The electricity is produced in a coil of wire called an armature during its rapid rotation past the magnet poles. In the case of magneto-electricity this motion takes place past the poles of permanent magnets. In the case of dynamo-electricity the motion takes place past the poles of electromagnets.

In Fig. 28 is shown a well-known form of magneto-electric machine in which the electricity is produced in coils of wire placed on an armature, on their rapid rotation past the poles of a permanent magnet.

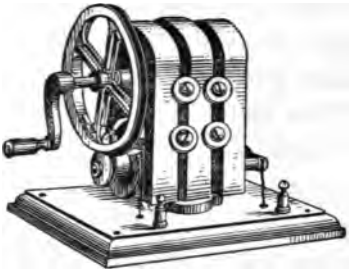

FIG. 28.—MAGNETO-ELECTRIC MACHINE.

In Fig. 29 is shown a well-known form of dynamo-electric machine. Here, on the rotation of the armature by the movement of a belt over the pulley shown to the right, powerful discharges required for lighting or power purposes are obtained.

Electricity is produced during the growth of both animals and plants. During active growth plants form an appreciable source of electricity.

Buff has shown that the roots and interior portions of plants are always negatively charged, while the flowers, fruits and green twigs are positively charged.

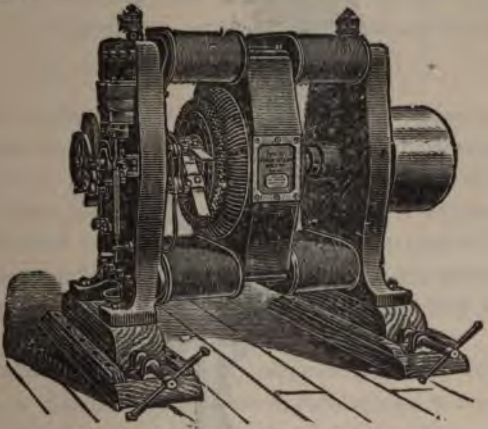

FIG. 29—DYNAMO-ELECTRIC MACHINE.

Plant tissues or fibres exhibit a true contraction on the passage of an electric discharge through them. Electricity is produced in the bodies of all animals during life. Some animals in addition to this electricity, which is essential to their life, possess the ability of producing sufficiently powerful discharges to serve as a protection against their enemies. This is the case both in the electric eel and the electric ray.

Fig. 30 shows the appearance of an electric ray. The electric organ of this animal is situated at the back of the head, and consists of hundreds of polygonal, cellular laminæ, supplied with numerous nerve fibres.

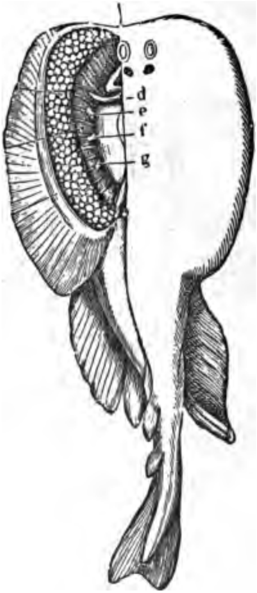

Fig. 30.—Electric Ray.

EXTRACTS FROM STANDARD WORKS.

John W. Urquhart, in his work on "Dynamo Construction,"* page 1, remarks as follows concerning the distinction between a dynamo-electric machine and a magneto-electric machine:

> The word "dynamo" has by the force of common usage become equivalent to the longer term dynamo-electric machine. But, as employed in connection with electricity, the abbreviated form is not likely to cause confusion. In the light of the rapid improvements of the past five years it seems unfortunate, however, that so apt a term as dynamo-electric machine should have only a limited application to electric generative machines.
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> Although it was originally proposed by Dr. Werner Siemens to distinguish an important development in the earlier form of power electrical machines, and served the purpose very well at that time, yet the progress of electrical invention exhibits at the present day greater differences between the two "dynamos" than ever existed between the early magneto-machine and its self-energizing offspring.
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> *Any machine moved by mechanical means, and adapted to convert the power of motion into the energy of electricity, may be called a dynamo.* The older magneto-electric

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machines effected nothing less than this, yet *a Magneto-Electric Machine*—an apparatus in which steel magnets are used to furnish the "magnetic field"—is not strictly, by common consent, regarded as a dynamo.

A dynamo is really a magneto-electric machine in which the "field" is maintained by that form of iron magnet called electro, *the electromagnet being "electrified" or excited by the current of the machine itself.*

Magneto-electric machines are an almost obsolete type. Every year renders the distinction between them and dynamos less marked, and they are gradually becoming recognized as merely an old-fashioned pattern of the dynamo.

The duty of the dynamo is the conversion of one form of energy into another form of energy. But it has been discovered that a dynamo is a reversible machine. When it is driven by a steam engine, it returns a large proportion of the power expended upon it in the form of an electric current. When, on the contrary, the dynamo is "fed" with an electric current, it becomes itself a *motor*. *An electric motor* is merely a dynamo with its function reversed. While in the first sense it is dynamo-electric, in the second sense it becomes electro-dynamic. The dynamo may thus be regarded as a machine which is adapted either to convert mechanical energy into electricity, or electrical energy into mechanical power.

V.—ELECTRO-RECEPTIVE DEVICES.

In the commercial applications of electricity various electric sources are employed in order to obtain one or another of the electrical effects produced by the passage of electric discharges. These effects are produced by the passage of the discharge through a variety of apparatus called electro-receptive or translating devices.

A thorough understanding of the operation of the various electro-receptive devices cannot be had without considerable knowledge of the principles of electric science. In order, however, to become acquainted with the many purposes for which electricity is employed in the arts, a general description of some of the most important electro-receptive devices will be given.

Electro-receptive devices consist essentially of contrivances placed in or near the path of an electric discharge so as to be traversed or influenced by such discharge. Such devices, on the passage of a discharge through them, or, on their being influenced by the neighborhood of such discharges, have produced in them various mechanical, thermal, luminous, magnetic, chemical or physiological effects.

A convenient classification of electro-receptive devices is based on the character of the effects which such devices are intended to produce.

It is a well known principle in science that energy must be expended in order to produce any phenomenon. In none of the changes to which matter is subject can energy be annihilated. It may disappear in one form, but only to reappear in some other form. Excellent examples of this principle are seen in the expenditure of various forms of energy, in the different varieties of electric sources, for the production of electricity.

In the same manner the expenditure of electrical energy, during the passage of a discharge through a conductor, results in the production of various other forms of energy, as is witnessed by the different kinds of effects produced.

Various mechanical effects are produced by the passage of a discharge through a conductor. One of the most important applications of such is seen in the electric motor.

A well-known form of electric motor, suitable for purposes where a small amount of energy is required, is shown in Fig. 31. Such an electric motor is practically of the same general construction as a dynamo-electric machine. When, however, electricity is passed through the motor, a rapid rotation of its armature is produced. In point of fact a dynamo-electric machine may be employed as a motor; for, if an electric discharge be sent through the machine, its armature will rotate and furnish mechanical power.

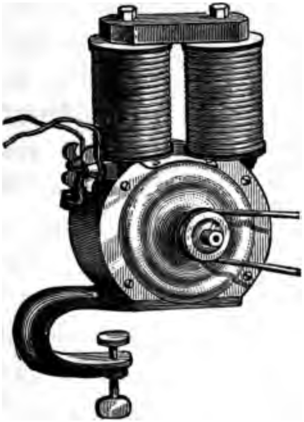

FIG. 31.—ELECTRIC MOTOR.

One of the great advantages which results from the use of electricity as a motive power comes from the ease with which considerable energy can be transmitted from one place to another, even though such places be great distances apart. Suppose, for example, that it is required to utilize the power of a waterfall, situated say 10 or 20 miles outside a city, or other location, at which the mill or factory, whose machinery is to be driven, is situated. By the electric transmission of power, it is only necessary to employ a water wheel to drive a dynamo-electric machine and to send the electric discharges so produced through a wire or conductor connecting the dynamo with an electric motor at the distant place.

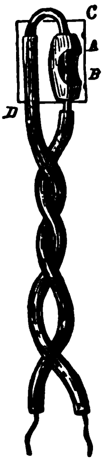

FIG. 32.—ELECTRIC FUSE.

When a disruptive discharge occurs, heat is produced. This heat is used in some forms of electric fuses for the ignition of a fuse by means of which a charge is fired. An electric fuse, therefore, forms an example of an electro-receptive device operated by the heat of a discharge. Such an electric fuse is shown in Fig. 32, in which a covered conductor, *C*, leads the discharge to a break or gap between two platinum terminals at *A B*. The spark at this point causes the ignition of the powder, or of a primer of gun cotton.

The electric heater forms another example of an electro-receptive device in which the heating power of the discharge is utilized. The electric heater consists essentially of a wire or other conductor which, possessing considerable resistance, becomes highly heated by the passage of an electric discharge.

Examples of electro-receptive devices, which depend for their operation on the luminous effects produced by a discharge, are seen in the arc and incandescent electric lamps.

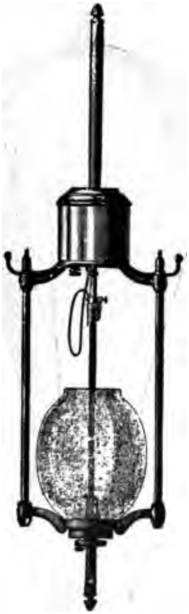

FIG. 33.—ARC LAMP.

A simple form of arc lamp is shown in Fig. 33. A voltaic arc is produced between two carbon points or electrodes that, during their consumption, are maintained at a constant distance apart by means of a regulating device operated by electro-magnets. The device is placed in the box shown in the upper part of the lamp.

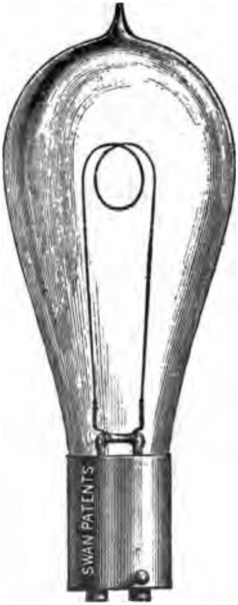

FIG. 34.—INCANDESCENT ELECTRIC LAMP.

In the incandescent electric lamp shown in Fig. 34, a filament of carbon, shaped as shown, is raised to incandescence by the passage through it of an electric discharge. In order to prevent the incandescent carbon from being rapidly consumed, and thus decreasing the life, or efficient existence, of the lamp, the lamp chamber is exhausted of nearly all the air it originally contained.

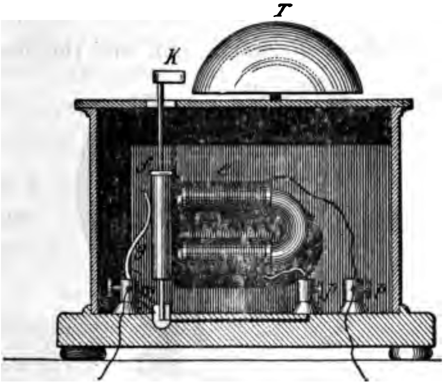

FIG. 35.—ELECTRO-MAGNETIC BELL.

The magnetic effects of an electric discharge are, perhaps, used in a greater variety of electro-receptive devices than any other effect.

An electro-magnet consists essentially of coils of insulated wire wrapped around a core of soft iron. When the coils are traversed by an electric discharge the core is rendered strongly magnetic and would tend to attract any mass of iron held near it. As soon as the discharge ceases to pass through the coils, the core loses its magnetism. If, therefore, an easily movable mass of soft iron, called an armature, be placed near the electromagnet, but prevented from actually touching it by the action of a spring, on alternately starting and stopping the discharge through the coils, the armature, under the alternate action of the force of magnetism and the elasticity of the spring, will be alternately drawn toward and away from the electromagnet, or will have a rapid to-and-fro motion produced in it.

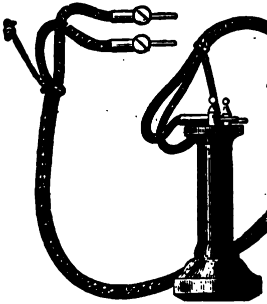

Fig. 36.—Telephone.

In the electro-magnetic bell shown in Fig. 35, a hammer, K, is attached to the soft iron armature of the electro-magnet e. On rapidly intermitting the discharge through the coils of the electromagnet, the bell is rung by the to-and-fro motions of the armature.

Exceedingly valuable applications of electromagnets are seen in telegraphic and telephonic apparatus.

A form of telephone is shown in Fig. 36. In this well-known form of apparatus a flexible diaphragm of sheet iron is supported near the poles of a steel magnet, around one end of which a coil of insulated wire is wrapped. If a person talks against the diaphragm, the sound waves cause it to move toward and from the magnetic pole. These to-and fro motions produce, in the coil of wire wrapped thereon, electric charges that are sent into a line or conductor which runs to a distant station, where it is connected to a receiving instrument. As the discharges pass through the coils of wire wrapped around the poles of the receiving instrument, they produce in its diaphragm to-and-fro motions exactly similar to those produced by the sound waves in the diaphragm of the transmitting instrument.

Any one listening, therefore, at the diaphragm of the receiving instrument will hear all that has been spoken into the transmitting instrument.

There are many forms of electro-receptive devices that are operated by the chemical effects of the electric discharge. An uncharged storage battery is an example of one of such devices. A well-known form of storage battery is shown in Fig. 37. The electric

Electric charges can be produced by differences of temperature. If a short cylinder of bismuth, *J*, be placed as shown in Fig. 26, in a gap in the hollow rectangle of copper *A B*, and the rectangle be unequally heated, as by the flame *F*, of an alcohol lamp placed as shown, a constant electric discharge will pass through the metallic path provided by the rectangle, and the magnetic needle *M*, will be deflected by such discharge.

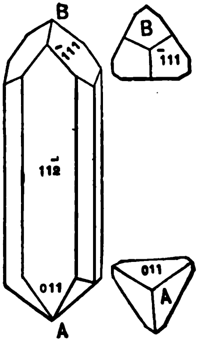

FIG. 27.—PRODUCTION OF PYRO-ELECTRICITY.

Here electricity is produced by differences of temperature. If all parts of the rectangle were equally heated, no electricity would be produced.

Electricity produced in this manner by differences of temperature is called thermo-electricity.

When certain crystalline bodies are unequally heated, electricity is produced as long as they remain unequally heated.

If, for example, a crystal of a mineral called tourmaline be unequally heated, one end of the crystal will, while the temperature is rising, acquire a positive charge, and the other end a negative charge. While the temperature of the crystal is falling, opposite charges are produced. Such a crystal is shown in Fig. 27. The end *A*, which acquires a positive electrification while the temperature of the crystal is rising, is called the analogous pole. The opposite end *B*, is called the antilogous pole.

A heated tourmaline crystal, if suspended by a silk fibre, will be attracted or repelled by a second heated tourmaline, like any other charged body.

Electricity produced in this way, in crystalline bodies, by differences of temperature is called pyroelectricity.

At the present time nearly all the powerful electric discharges required for the production of electric light or power are obtained by the motion of conductors past the poles of permanent or electromagnets.

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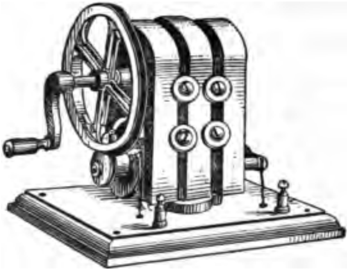

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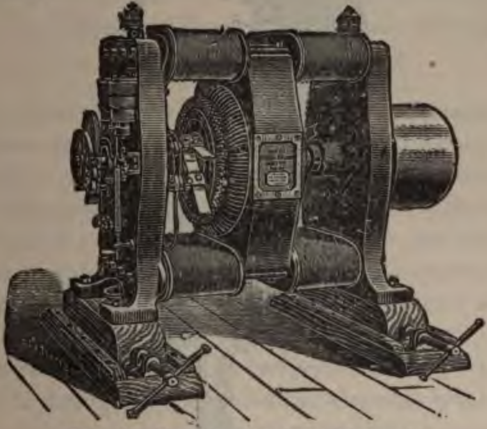

FIG. 29—DYNAMO-ELECTRIC MACHINE.

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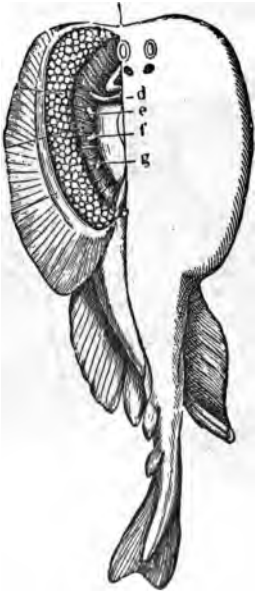

FIG. 30.—ELECTRIC RAY.

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machines effected nothing less than this, yet *a Magneto-Electric Machine*—an apparatus in which steel magnets are used to furnish the "magnetic field"—is not strictly, by common consent, regarded as a dynamo.

A dynamo is really a magneto-electric machine in which the "field" is maintained by that form of iron magnet called electro, *the electromagnet being "electrified" or excited by the current of the machine itself.*

Magneto-electric machines are an almost obsolete type. Every year renders the distinction between them and dynamos less marked, and they are gradually becoming recognized as merely an old-fashioned pattern of the dynamo.

The duty of the dynamo is the conversion of one form of energy into another form of energy. But it has been discovered that a dynamo is a reversible machine. When it is driven by a steam engine, it returns a large proportion of the power expended upon it in the form of an electric current. When, on the contrary, the dynamo is "fed" with an electric current, it becomes itself a *motor*. *An electric motor* is merely a dynamo with its function reversed. While in the first sense it is dynamo-electric, in the second sense it becomes electro-dynamic. The dynamo may thus be regarded as a machine which is adapted either to convert mechanical energy into electricity, or electrical energy into mechanical power.

V.—ELECTRO-RECEPTIVE DEVICES.

In the commercial applications of electricity various electric sources are employed in order to obtain one or another of the electrical effects produced by the passage of electric discharges. These effects are produced by the passage of the discharge through a variety of apparatus called electro-receptive or translating devices.

A thorough understanding of the operation of the various electro-receptive devices cannot be had without considerable knowledge of the principles of electric science. In order, however, to become acquainted with the many purposes for which electricity is employed in the arts, a general description of some of the most important electro-receptive devices will be given.

Electro-receptive devices consist essentially of contrivances placed in or near the path of an electric discharge so as to be traversed or influenced by such discharge. Such devices, on the passage of a discharge through them, or, on their being influenced by the neighborhood of such discharges, have produced in them various mechanical, thermal, luminous, magnetic, chemical or physiological effects.

A convenient classification of electro-receptive devices is based on the character of the effects which such devices are intended to produce.

It is a well known principle in science that energy must be expended in order to produce any phenomenon. In none of the changes to which matter is subject can energy be annihilated. It may disappear in one form, but only to reappear in some other form. Excellent examples of this principle are seen in the expenditure of various forms of energy, in the different varieties of electric sources, for the production of electricity.

In the same manner the expenditure of electrical energy, during the passage of a discharge through a conductor, results in the production of various other forms of energy, as is witnessed by the different kinds of effects produced.

Various mechanical effects are produced by the passage of a discharge through a conductor. One of the most important applications of such is seen in the electric motor.

A well-known form of electric motor, suitable for purposes where a small amount of energy is required, is shown in Fig. 31. Such an electric motor is practically of the same general construction as a dynamo-electric machine. When, however, electricity is passed through the motor, a rapid rotation of its armature is produced. In point of fact a dynamo-electric machine may be employed as a motor; for, if an electric discharge be sent through the machine, its armature will rotate and furnish mechanical power.

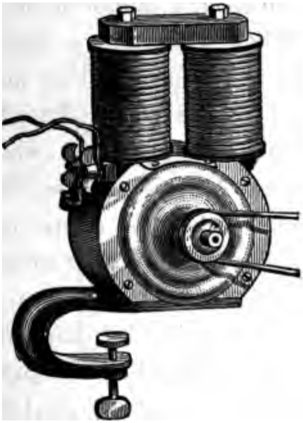

FIG. 31.—ELECTRIC MOTOR.

One of the great advantages which results from the use of electricity as a motive power comes from the ease with which considerable energy can be transmitted from one place to another, even though such places be great distances apart. Suppose, for example, that it is required to utilize the power of a waterfall, situated say 10 or 20 miles outside a city, or other location, at which the mill or factory, whose machinery is to be driven, is situated. By the electric transmission of power, it is only necessary to employ a water wheel to drive a dynamo-electric machine and to send the electric discharges so produced through a wire or conductor connecting the dynamo with an electric motor at the distant place.

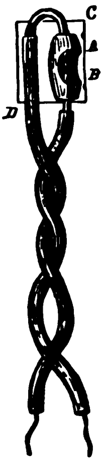

FIG. 32.—ELECTRIC FUSE.

When a disruptive discharge occurs, heat is produced. This heat is used in some forms of electric fuses for the ignition of a fuse by means of which a charge is fired. An electric fuse, therefore, forms an example of an electro-receptive device operated by the heat of a discharge. Such an electric fuse is shown in Fig. 32, in which a covered conductor, *C*, leads the discharge to a break or gap between two platinum terminals at *A B*. The spark at this point causes the ignition of the powder, or of a primer of gun cotton.

The electric heater forms another example of an electro-receptive device in which the heating power of the discharge is utilized. The electric heater consists essentially of a wire or other conductor which, possessing considerable resistance, becomes highly heated by the passage of an electric discharge.

Examples of electro-receptive devices, which depend for their operation on the luminous effects produced by a discharge, are seen in the arc and incandescent electric lamps.

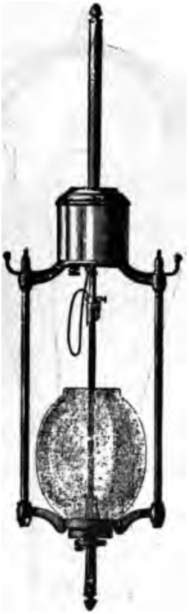

FIG. 33.—ARC LAMP.

A simple form of arc lamp is shown in Fig. 33. A voltaic arc is produced between two carbon points or electrodes that, during their consumption, are maintained at a constant distance apart by means of a regulating device operated by electro-magnets. The device is placed in the box shown in the upper part of the lamp.

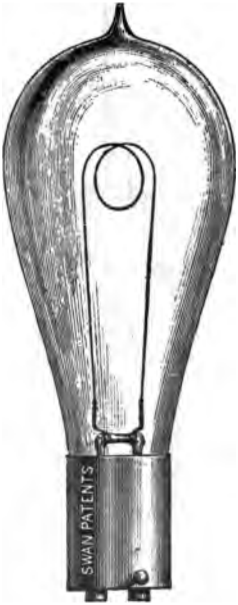

FIG. 34.—INCANDESCENT ELECTRIC LAMP.

In the incandescent electric lamp shown in Fig. 34, a filament of carbon, shaped as shown, is raised to incandescence by the passage through it of an electric discharge. In order to prevent the incandescent carbon from being rapidly consumed, and thus decreasing the life, or efficient existence, of the lamp, the lamp chamber is exhausted of nearly all the air it originally contained.

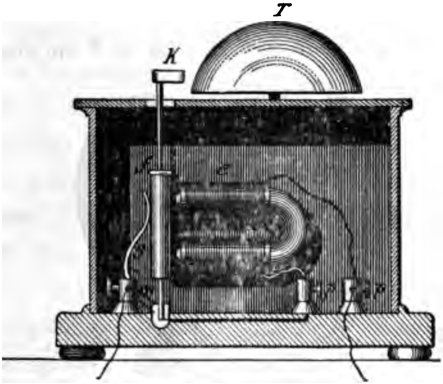

FIG. 35.—ELECTRO-MAGNETIC BELL.

The magnetic effects of an electric discharge are, perhaps, used in a greater variety of electro-receptive devices than any other effect.

An electro-magnet consists essentially of coils of insulated wire wrapped around a core of soft iron. When the coils are traversed by an electric discharge the core is rendered strongly magnetic and would tend to attract any mass of iron held near it. As soon as the discharge ceases to pass through the coils, the core loses its magnetism. If, therefore, an easily movable mass of soft iron, called an armature, be placed near the electromagnet, but prevented from actually touching it by the action of a spring, on alternately starting and stopping the discharge through the coils, the armature, under the alternate action of the force of magnetism and the elasticity of the spring, will be alternately drawn toward and away from the electromagnet, or will have a rapid to-and-fro motion produced in it.

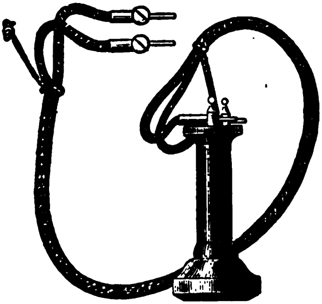

FIG. 36.—TELEPHONE.

In the electro-magnetic bell shown in Fig. 35, a hammer, *K*, is attached to the soft iron armature of the electro-magnet *e*. On rapidly intermitting the discharge through the coils of the electromagnet, the bell is rung by the to-and-fro motions of the armature.

Exceedingly valuable applications of electromagnets are seen in telegraphic and telephonic apparatus.

A form of telephone is shown in Fig. 36. In this well-known form of apparatus a flexible diaphragm of sheet iron is supported near the poles of a steel magnet, around one end of which a coil of insulated wire is wrapped. If a person talks against the diaphragm, the sound waves cause it to move toward and from the magnetic pole. These to-and fro motions produce, in the coil of wire wrapped thereon, electric charges that are sent into a line or conductor which runs to a distant station, where it is connected to a receiving instrument. As the discharges pass through the coils of wire wrapped around the poles of the receiving instrument, they produce in its diaphragm to-and-fro motions exactly similar to those produced by the sound waves in the diaphragm of the transmitting instrument.

Any one listening, therefore, at the diaphragm of the receiving instrument will hear all that has been spoken into the transmitting instrument.

There are many forms of electro-receptive devices that are operated by the chemical effects of the electric discharge. An uncharged storage battery is an example of one of such devices. A well-known form of storage battery is shown in Fig. 37. The electric discharge is passed between two lead plates immersed in dilute sulphuric acid. On its passage, chemical actions are produced in these plates that enable them, when the discharge ceases to pass, to furnish an electric discharge like an ordinary voltaic battery.

Another variety of electro-receptive device, depending for its action on the chemical effects of the discharge, is seen in a plating bath.

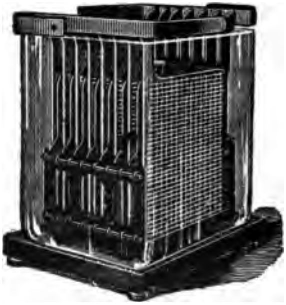

FIG. 37.—STORAGE BATTERY.

The articles to be plated are immersed in a bath, containing a solution of a salt of silver, by suspending them from a suitably supported metallic rod. This rod is connected to one of the terminals of an electric source, the other terminal of which is connected to a similar metallic rod from which is suspended a plate of silver.

As the discharge of the battery passes through the liquid the silver is slowly dissolved from the silver plate and deposited in a firmly adherent layer on the articles to be plated.

A plating or coating so obtained is called an electroplating.

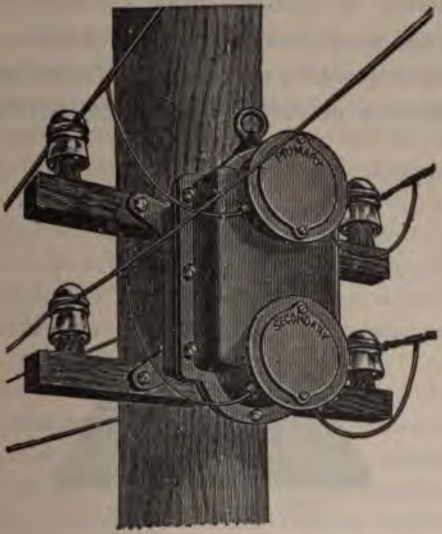

FIG. 38.—TRANSFORMER.

Besides the electro-receptive devices already mentioned, there are a great variety of others.

A device called a transformer is shown in Fig. 38. A transformer is a device by means of

EXTRACTS FROM STANDARD WORKS.

Urquhart, in his "Electric Light Fitting,"* page 88, speaks thus of the advantages possessed by arc lighting:

A great deal of the trouble that has hitherto been encountered in the general utilization of arc lamps has arisen from ignorance on the part of those fitting up the circuit for or attending to the arc lamps. Now that the lamps and currents are becoming better known more skilled attention is given to them, and a great impetus has thereby been imparted to arc lighting. It may also be pointed out that the revival of arc lighting (which until lately appeared likely to be eclipsed by incandescent lighting) is due in a considerable degree to improvements in the lamps themselves, to more effective insulators, superior methods of automatic regulation at the dynamos, and to a better quality of carbons.

The wonderful cheapness of the arc light, compared to the incandescent light, would prove a strong inducement to many to adopt it in place of gas, were it practical to obtain, in ordinary commerce, plants that could be depended upon to yield a *reliable* and *steady* light. The general opinion of the arc light was, until very lately, that it has not yet passed the experimental stage, and that it was, in consequence, erratic and unreliable.

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* "Electric Light Fitting," a Handbook for Working Electrical Engineers, by John W. Urquhart. London: Crosby, Lockwood & Co. 1890. 226 pages, 89 illustrations. Price, $2.00.

It should now be the aim of every one interested in the new light to remove that impression, and to assist in spreading the general conviction that arc lighting can be depended upon ; that it is inexpensive and safe.

This can only be effected by first understanding the nature of the arc lighting current, the nature of the dynamo producing it, the best means of controlling it, the most effective method of distributing the light, and the working and care of the lamp itself. In one item alone (carbons) the cost of running the light has recently been greatly reduced. And by such improvements as the substitution of a laminated for a solid armature core in a dynamo, the cost of the light has been reduced by one-third.

When arc lamps run from dynamos were first brought into use only one lamp could be put into the circuit of one machine. This was justly considered a great bar to the diffusion of the light, and altogether a costly system, necessitating as it did powerful lamps, only suitable to restricted areas. When Jablochkoff introduced his electric candle it was thought that arc lamps were entirely superseded, since several candles could be burned in the circuit of one dynamo. But an improvement was soon effected in the arc lamp, which opened up a means for putting any number into the circuit of one machine. We may glance at the early form and the improved form.

VI.—ELECTRIC CURRENT.

When the charge on any body is passed into another body, or in other words, when an electric discharge occurs, an electric current is produced.

As we have already seen, the amount of the electric discharge varies greatly in different cases. Some discharges are powerful, while others are quite weak. The strength of an electric current depends on the quantity of electricity which passes through the conducting path by means of which the electricity is transferred from the charged body to the body that is to receive its charge.

An electric current may, therefore, be defined to be the quantity of electricity which passes through a conductor in a given time ; or, more precisely, as the rate at which a definite quantity of electricity passes through a conductor or circuit.

An electric discharge, therefore, is the same as an electric current, and the effects already mentioned as the effects of electric discharges are also the effects of electric currents, viz.:

(1.) Mechanical.
(2.) Thermal.
(3.) Luminous.
(4.) Magnetic.
(5.) Chemical.
(6.) Physiological.

The object of electric sources is to produce by means of discharges or currents some of these effects in various electro-receptive devices through which the currents pass. In order to permit this passage of the current through the electro-receptive devices, the devices are connected with the electric sources by means of suitable conducting paths. Such a path forms what is called an electric circuit.

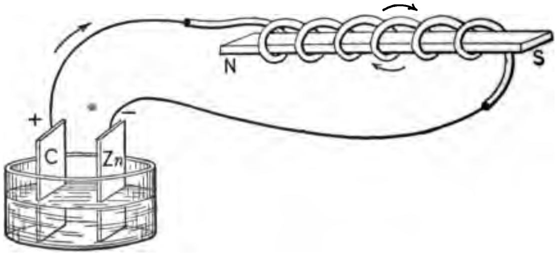

FIG. 40.—AN ELECTRIC CIRCUIT.

The electricity flows or passes out of the electric source, enters the circuit, and, after passing through the electro-receptive devices placed therein, returns by the way of the circuit back again to the source.

The connections of an electric source, a conducting path, and an electro-receptive device to one another so as to form a circuit, are shown in Fig. 40. Here the source is represented as a voltaic cell, and the electro-receptive device as an electromagnet.

The point or place in a source from which the current flows out into the circuit, and the point where it again enters the source, after having passed through the circuit, are called the poles of the source.

Since the electricity which leaves the source and enters the circuit always again enters the source after flowing through the circuit, all sources must necessarily possess two poles; viz., the pole where it leaves the source and the pole where it re-enters it. These poles are called the positive and the negative poles.

As a matter of convenience it is assumed that the electric current passes out of a source at its positive pole and enters it at its negative pole. The symbols + and — are employed to represent the positive and negative poles respectively. Thus, in Fig. 40, the current is represented as leaving the voltaic cell at the plate *C*, or at the + pole, and, entering the circuit, taking the path indicated by the arrows. After passing through the coils of the electromagnet *N S*, placed therein, it again enters the source at the — pole, or at the plate marked *Zn*.

This view, which is now generally accepted, regards electricity as consisting of a single flow. In the opinion of some, however, two opposite currents, of positive and negative electricities respectively, are regarded as flowing through every circuit. This latter view appears both unnecessary and improbable.

The points or places on an electro-receptive device at which the current respectively enters and passes out are also called poles. As the current enters the electro-receptive device at one pole and leaves it at another pole, all electro-receptive devices must necessarily possess at least two poles.

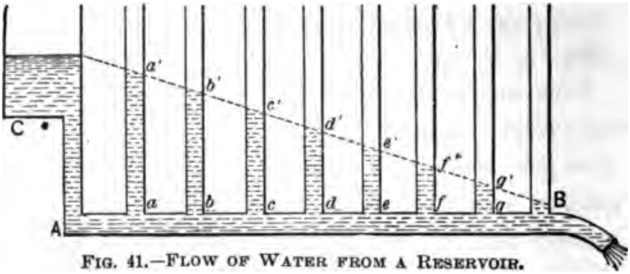

FIG. 41.—FLOW OF WATER FROM A RESERVOIR.

That pole of an electro-receptive device which is connected to the positive pole of a source is called the positive pole of the device. That pole which is connected to the negative pole of a source is called the negative pole of the device.

This, as will be seen, differs from the usage as regards an electric source. It can be readily remembered, however, that the pole of an electro-receptive device has always the same name as the pole of the source with which it is connected.

In order to obtain clearer notions concerning the flow of electricity through conductors, we may consider the corresponding case of the flow of water through pipes. Suppose the reservoir or source of water shown in the vessel *C*, Fig. 41, be placed in communication with the horizontal pipe *A B*, and that this pipe is furnished with open, vertical pipes at *a*. *b*, *c*, *d*, *e*, *f*, *g* and *B*. While the outlet of the pipe at *B*, is closed, the level of the water in the connecting tubes will be the same as it is in the source. If, however, the water be allowed to escape from the opening *B*, the level of the water will be found on the inclined dotted line, or at a', b', c', d', e', f', g', or, on what is called the hydraulic gradient. The pressure per-square-inch at any cross section of a horizontal pipe is measured by the height of the liquid in the horizontal pipe, and decreases in the direction in which the liquid is flowing.

The force which urges the liquid through the pipe between any two points is measured by the difference of pressure between these two points, and may be called the *water-motive force.*

Consider now the corresponding case of an electric source, such, for example, as the dynamo-electric machine shown in Fig. 42. Here the dynamo *D*, is represented as having one of its poles joined to the earth-connected plate at *E*. The current produced is supposed to flow or pass out of the source at *A*, to enter and pass through the conductor *A B*, and to return to the source by way of the ground plates *E' E*.

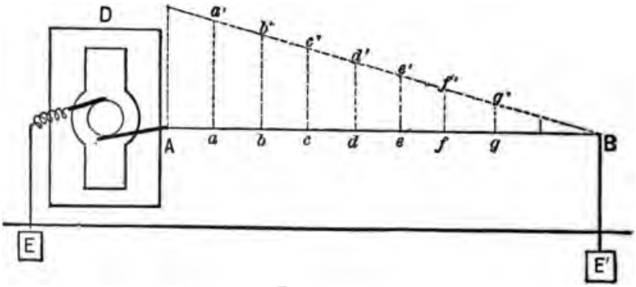

FIG. 42.—FLOW OF ELECTRICITY FROM SOURCE.

In carrying out the resemblance between this and the preceding figure, we may regard the dynamo-electric machine as a pump that is raising electricity from a lower to a higher level and continuously passing it through the conductor *A B*, from *A*, to *B*. The electric pressure or potential producing the flow is greatest near the dynamo, and least at the furthest end, the difference at the points *a, b, c, d, e, f, g*, being represented by the vertical lines *aa'*, *bb'*, *cc'*, *dd'*, *ee'*, *ff'*, and *gg'*.

The term electric pressure or potential is used very frequently in electricity. Electricity flows between any two points, such, for example, as *A* and *B*, in virtue of, or on account of the difference of electric potential or pressure between these two points, or on account of the difference of level between them.

Just as we called the force that causes the water to flow from the reservoir through the pipes connected therewith the *water-motive force,* we call the force, which causes the electricity to flow through the circuit connecting the electric source with the electroreceptive device, the *electromotive force ;* or, as it is frequently written, the E. M. F.

The electromotive force may, therefore, be defined as the force which causes electricity to flow, or to tend to flow, through a circuit.

In the case of the vessel filled with water at a higher level than the level at which the water escapes, the flow decreases as the water falls in the vessel. The flow continues only while there exists a difference of level, or, in other words, the flow is but momentary. This is generally the case where a charged body is discharged by connection to the earth.

Electric sources, however, not only produce but also maintain a difference of potential.

In the case of the flow of liquid through a pipe, if a continuous current of the liquid be maintained from the higher level in the reservoir to a lower level, as, for example, by means of a pump, it must be forced to flow through the pump to the reservoir, from the lower level toward the higher level.

In case of an electric source, since the thing called electricity flows through a closed circuit, if its direction of flow in that part of the circuit external to the source—*i. e.*, in the external or useful circuit—be from a higher to a lower level, then its flow through the remainder of the circuit—*i. e.*, through the source—must be from the lower to the higher level. Since, however, the electrical potential of a body represents the work the electricity is capable of doing, the work done by the electricity may be regarded as being that done when it passes from the higher to the lower level.

The value of the strength of the current, which is passing in any circuit, may be determined by means of a very important principle first announced by Dr. Ohm, and known as Ohm's law. This principle may be expressed as follows: The current strength in any circuit is directly proportional to the electromotive force and inversely proportional to the resistance:

$$C = \frac{E}{R}$$

Calling C the current strength, E, the electromotive force and R, the electrical resistance, or the thing that opposes the passage of electricity through a circuit, Ohm's law may be represented by the foregoing formula.

From this formula it is evident that the greater the value of E, the electromotive force, and the smaller the value of R, the resistance, the greater is the value of C, the current.

We have already seen that an electric circuit necessarily consists of three parts; namely,

(1.) Of an electric source or sources.

(2.) Of the leads or conductors which connect the sources with the electro-receptive devices.

(3.) Of the various electro-receptive devices that are placed in the circuit and are energized by the passage of the current.

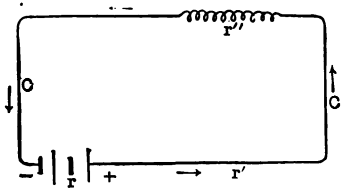

FIG. 43.—AN ELECTRIC CIRCUIT.

Each of these parts of the circuit offers an electric resistance to the passage of the current through it.

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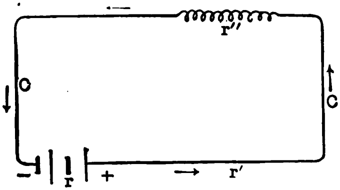

FIG. 43.—AN ELECTRIC CIRCUIT.

Each of these parts of the circuit offers an electric resistance to the passage of the current through it.

Calling the resistance of the source r, as represented in Fig. 43, that of the leads or conductors r', and that of the electro-receptive device r'', the current strength in the circuit is represented by Ohm's law as follows :

$$C = \frac{E}{r + r' + r''}.$$

In order to cause a current of a certain strength to flow through any circuit notwithstanding an increase in the resistance of that circuit, it is evident that the value of the pressure or electromotive force must be correspondingly increased. Different electric sources vary greatly from one another in the ease with which the value of the electromotive force they furnish may be increased.

It should be borne in mind that although in the preceding Primers we have spoken of the various electric sources as producing electricity, yet, in point of fact, what they in reality produce are differences of potential. When their poles, at which these differences of potential are greatest, are connected by means of a conductor, a current is produced in such conductor, the value of which will depend on the value of the electric resistance of the circuit.

EXTRACTS FROM STANDARD WORKS.

W. E. Ayrton, in his "Practical Electricity,"* page 1, speaks thus of the electric current:

In the various industries in which electricity is employed, as in the telegraph, telephone, electric lighting, electrotyping, electroplating, torpedo exploding and in the working of machinery by the aid of electromotors, it is the so-called "*electric current*" that is made use of. Hence a knowledge of the laws of this electric current, a clear conception of its so-called properties, combined with a practical acquaintance with the modes of measuring it, must be of especial importance for a right understanding of the working of the apparatus employed in the above mentioned industries. Indeed, such knowledge is absolutely necessary if the user of electrical apparatus is desirous of employing it to the best advantage, of being able to correct faults when they occur, as well as of effecting improvements in the instruments themselves.

It is customary to speak of an electric current as if it had an independent existence apart from the "*conductor*" through which it is said to be flowing, just as a current of water is correctly spoken of as something quite distinct from the pipe through which it flows. But in reality we are sure neither of the direction of flow of an electric current,

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* "Practical Electricity; A Laboratory and Lecture Course, for First Year Students of Electrical Engineering, Based on the Practical Definitions of the Electrical Units." by W. E. Ayrton. London: Cassell & Co., Limited. 1888. 516 pages, 180 illustrations, Price, $2.50.

nor whether there is any motion of anything at all. And the student must not assume that the conventional expression, "the current flows through the copper pole of a galvanic battery to the zinc pole through the external circuit," implies any knowledge of the real direction of flow any more than the railway expressions, "up train" and "down train," mean that either train is necessarily going to a higher level than the other. In the case of a stream of water flowing along a river bed, we are quite certain that there is water in motion, and every one is agreed as to which way the water is flowing; a cork or a piece of wood thrown on the water indicates by its motion the direction in which the water is moving.

Nor, again, must an electric current be supposed to be like waves of sound traveling along, since in this latter case, although there is no actual traveling along of matter, still the direction of motion of the waves of sound is perfectly definite. Indeed, a wire along which an electric current is flowing is more like a wire at each end of which a musical instrument is being played, so that the sound is traveling in both directions along the wire at the same time. In short, the statement that an electric current is flowing along a wire is only a short way of expressing the fact that the wire and the space around the wire are in a different state from that in which they are when no electric current is said to be flowing. So that when a body and the space around the body possess certain properties that they do not usually possess, an electric current is said to be flowing through that body.

VII.—ELECTRIC UNITS.

Exact measurement of any magnitude is obtained by reference to certain units or values which have been carefully determined. Thus the distance between any two points is measured by reference to certain units of length, such, for example, as the foot, mile, etc. The weight of a body, or more properly speaking its mass, is determined by reference to some unit of weight or mass, such, for example, as the grain, pound, ton, etc. The duration of a phenomenon is determined by reference to certain units of time, such as the second, minute, hour, year, etc.

These units are called respectively the units of weight, length and time.

In the same way certain units are used in the measurement of electricity. In the case of electric units the units of length, mass and time are taken as the centimetre, the gramme and the second. For this reason such units are often called C. G. S. units, or the centimetre-gramme-second units.

The metre is the French unit of length. It is equal to 39.37079 English inches. The metre is intended to be equal to the $\frac{1}{40,000,000}$ of a meridian circle of the earth. The centimetre is equal to $\frac{1}{100}$ of a metre, or to .3937079 English inch.

The gramme is the French unit of mass. It is based on the metrical system and is equal to the weight of a cubic centimetre of pure water at the temperature of its maximum density, namely, at the temperature of 39.2° F., or 4° C. The gramme is equal to 15.43235 English grains, or .0022046 avoirdupois pound.

The second, or the unit of time, is equal to the $\frac{1}{86,400}$ part of a mean solar day.

The expression for Ohm's law

$$C = \frac{E}{R}$$

is generally read as follows; viz., The current strength in any circuit is equal to the electromotive force divided by the resistance.

In order to give fixed values to the quantities represented in this formula, certain unit values are given to the current C, the electromotive force E, and the resistance R. In determining or limiting these values, certain other unit values are introduced. In this way arises a variety of electrical units

The electrical units are based primarily on the values of the C. G. S. units. Unfortunately, however, they are so exceedingly small in some cases, and so exceedingly large in others, that in actual practice they have been replaced by certain multiple or decimal values. These units so obtained are called the practical electrical units.

The practical unit of electric current is called the ampère.

The practical unit of electromotive force is called the volt.

The practical unit of electric resistance is called the ohm.

Substituting these names for the symbols employed in the well-known expression:

$$C = \frac{E}{R}, \text{ we have,}$$

$$\text{The ampères} = \frac{\text{The volts}}{\text{The ohms}}.$$

The ampère, or the practical unit of the electric current, is such a rate of flow, or transmission of electricity, as would pass through a circuit whose resistance is one ohm, when under an electromotive force of one volt.

We may also define the value of the ampère by the amount of chemical decomposition it effects in a given time. We find in this way that an ampère is such a current as will deposit .00111815 gramme of silver per second, or .00009326 gramme of dilute sulphuric acid per second.

If we compare the rate of flow of electricity with the analogous case of the flow of water, we will see that the electric current represents the passage or flow in a given time of a certain quantity or amount of the thing called electricity.

In the case of liquids we measure the rate of flow as being equal to so many cubic inches or cubic feet per second. So too, in the case of the electric current, we measure the rate of flow of the thing called electricity as being equal to so many units of quantity of electricity per second.

The practical unit of electrical quantity is called the coulomb.

The coulomb is such an amount of electricity as would pass in one second, under an electromotive force of one volt, through a circuit whose resistance is equal to one ohm.

But, as we have already seen, the ampère is such a rate of flow as would pass under an electromotive force of one volt, through a circuit whose resistance is one ohm. An ampère, therefore, is equal to one-coulomb-per-second.

The volt is the practical unit of electric pressure, or of electromotive force.

The volt is equal to the electromotive force that would be required to cause a current of one ampère to pass through a circuit whose resistance is one ohm.

The value of the electromotive force in any circuit is called the voltage of the circuit. As the voltage of a circuit increases, the current strength which passes through that circuit increases in a corresponding ratio. When the resistance of a circuit is great, the voltage must be increased proportionally, in order to cause the same amount of electricity to flow through such circuit in a given time.

The practical unit of electric resistance is called the ohm.

An ohm is a resistance equal to that of a column of mercury of approximately 106 centimetres in length, and one square millimetre in area of cross section at the temperature of 0° C.

Defined in the terms of the preceding units, an ohm is such a resistance as would limit the flow of electricity through a circuit, when under an electromotive force of one volt, to an ampère, or one-coulomb-per-second.

The electricity present in any conductor as a charge produces a difference of potential between that conductor and the earth, or, in other words, it raises or increases the potential of that conductor.

The ability of a conductor to receive a charge without having its potential raised beyond a certain amount corresponds to the case of a vessel being able to hold a certain quantity of liquid before it begins to overflow. This property of a conductor is called its capacity.

The practical unit of electric capacity is called the farad. A farad is such a capacity of a conductor as would enable it to hold a quantity of electricity equal to one coulomb, if put into it under a pressure of one volt.

Just as in the case of a gas, a quart vessel is capable of holding a quart of gas under unit pressure, say that of the atmosphere, so an electrical conductor, whose capacity is one farad, is capable of holding one coulomb of electricity when under an electromotive force of one volt.

It is often a cause of some perplexity to students to understand why there should be in electricity one unit of capacity to represent the size of a vessel or conductor, and another unit to represent the amount or quantity of electricity required to fill such vessel or conductor to a certain difference of level or electromotive force. But, in this respect, electricity, like a gas, acts as if it were compressible. Therefore the quantity required to fill a vessel or conductor will depend necessarily on the electromotive force under which it is placed in the vessel, as well as on the size of such vessel or conductor.

The unit of electric work is called the joule.

The unit of electric power is called the watt.

The names of the preceding practical units have been taken from the names of distinguished electricians who are no longer living.

The ampère, the practical unit of electric current, was named after Ampère, a distinguished French physicist, whose investigations in the domain of magnetism were of great benefit to science.

The volt, the practical unit of electromotive force, was named after Alexander Volta, who invented the voltaic pile.

The ohm, the practical unit of the electric resistance, was named after Dr. George Ohm, who announced the well-known law that bears his name.

The coulomb, the practical unit of electric quantity, was named after Charles A. Coulomb, who made elaborate investigations in both electricity and magnetism.

The joule, the practical unit of electric work, was named after Dr. James Prescott Joule, of Manchester, who, among other valuable contributions to electric science, ascertained the laws which determine the amount of heat developed in a conductor by the passage through it of an electric current.

The farad, the practical unit of electric capacity, was named after Michael Faraday, whose extended investigations in electricity and magnetism are recorded in his classic work entitled "Experimental Researches in Electricity."

The watt, the practical unit of electric power, was named after James Watt, who may be regarded as almost the creator of the steam engine.

Multiple or decimal divisions or subdivisions of the above practical units are indicated by certain prefixes. For example, meg or mega when prefixed to any of the preceding units indicates one million times, as megohm, one million ohms; megavolt, one million volts.

Micro, as a prefix, indicates the one-millionth part, as microfarad, the millionth of a farad; microvolt, the millionth of a volt.

Milli, as a prefix, means the one thousandth, as milliampère, the one-thousandth of an ampère.

The prefix kilo means one thousand, as kilowatt, one thousand watts; kilojoule, one thousand joules.

EXTRACTS FROM STANDARD WORKS.

T. D. Lockwood in his work, "Electrical Measurement,"* page 22, writes as follows concerning electric units:

We have now seen that the batteries by which electricity is developed, the conductors by which it is transferred, the instruments by which it is made useful, and the electric current itself, have certain properties, magnitudes, or qualities, which it is often necessary to measure in order that their working value may be properly estimated.

That we may be able to make such measurements and to state their results, it is essential that we have some standard terms, or units, which, when expressed, convey to the mind definite ideas, precisely as in measuring a distance we would say so many feet or miles; or, in express ing the flow of water, so many gallons per minute; or, in describing the contents of a solid block, as so many cubic feet.

Furthermore, when one substance has several properties or magnitudes, a different system of measurement is required for each magnitude; for, as in a cubic block of wood we should measure one of its sides by superficial measure, its contents by cubic measure, and its weight by still another system, and would state the result differently in each case, so the different electrical magnitudes each have their own units, in which the results are expressed.

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*"Electrical Measurement," by T. D. Lockwood. New York: J. H. Bunnell & Co. 1890. 137 pages, 32 illustrations. Price, $1.50.

Sometimes we find that the results of certain measurements are obtained by reference to several different magnitudes ; as, for example, when we time the speed of a horse or a locomotive, we take the length of the distance traversed and the time consumed in traveling that distance, and thus calculate the velocity by reference to both length and time. In certain electrical measurements we find it necessary to resort to the same process, and combine different units to obtain a definite result.

Designations have been given to the practical electrical units from the names of distinguished electricians and scientists. The unit of electromotive force is called the " volt," from Volta ; and the unit of resistance is called the "ohm," after Ohm, the German physicist and mathematician ; while the unit of current strength is called the ampère from the French philosopher of that name.

VIII.—ELECTRIC WORK AND POWER.

The units of electric work and power are based on the same general principles as are the units of work and power in general use in mechanics. Before studying the principles of electric work and power it will, therefore, be necessary to consider, to some extent, the general principles of mechanical work and power.

The term work, as used in mechanics, represents a quantity equal to the force, by the expenditure of which the work is done, multiplied by the distance through which such force acts.

The foot-pound may be taken as the practical unit of mechanical work.

A foot-pound is equal to the amount of work done or performed when a force of one pound is exerted through a distance of one foot. Thus if a weight of 100 pounds is raised through a distance of 10 feet, an amount of energy equal to 100 × 10 = 1,000 foot-pounds must be expended.

By the term power, as used in mechanics, is meant the force multiplied by the distance through which the force acts, multiplied by the time during which it continues to act. In other words, power is the rate of doing work, or the rate at which energy must be expended in order to do work. Thus, suppose the weight of 100 pounds, before referred to, be raised through a distance of 10 feet, in the time of one second. The power expended to do this would be equal to 1,000 foot-second-pounds.

A careful distinction must be drawn between work and power. Work is independent of the time; power is dependent on the time. For example, if a man raise a weight of one pound through a distance of 10 feet, he expends an amount of energy, or does an amount of work, equal to 10 foot-pounds. He may do this work, or expend this amount of energy, in one second, in one minute, in one hour, or in one year. In all cases, however, leaving out of consideration air resistance or friction, the amount of work done, or the amount of energy expended, is the same. Not so, however, the power, or rate of doing work, or the rate at which he is expending energy; for, if he does the work in one second, he will be expending energy at a rate sixty times greater than when he does it in one minute.

For commercial purposes the horse-power is generally taken as the unit of power.

A horse-power equals an expenditure of energy at the rate of 550 foot-pounds per second, 33,000 foot-pounds per minute, or 1,980,000 foot-pounds per hour.

The practical unit of electric work is called the joule; the practical unit of electric power is called the watt. To understand the principles on which they are based, we will consider the case of work done by means of water that has been raised to some higher level.

In the case of a liquid mass at different levels the liquid at the higher level possesses a certain ability to do work; or, in other words, possesses a certain amount of potential energy, which may be measured by the quantity of the liquid at the higher level, and by the excess of this height over that of the lower level, or, in other words, by the difference of height between these two levels. As the liquid flows toward the lower level, potential energy is lost and a certain amount of work is done.

In the case of electricity, the difference of electric level or potential between any two points of a conductor causes an electric current to flow between these points from the higher to the lower level, and during this flow electric potential energy is lost and work is done by the electric current.

In the case of a liquid, the amount of work done is equal to the amount of liquid which flows multiplied by the difference of level through which it flows.

As in the case of the flow of a liquid, the amount of work done by the electric current is measured by the amount of electricity that passes, multiplied by the difference of potential under which it passes or flows.

Unit quantity of electric work is therefore equal to unit quantity of electricity multiplied by unit difference of potential.

The practical unit of electric quantity is called the coulomb. The practical unit of electric pressure, or difference of potential, is called the volt. It would follow, therefore, that the product of the coulombs by the volts will correctly represent the amount of work done by the passage or flow of a certain quantity of electricity.

The practical unit of electric work is called the joule, or the volt-coulomb. It is equal to the product of one coulomb by one volt.

In order to deduce the practical unit of electric power from the practical unit of electric work, it is only necessary to remember that power is equal to work-per-second. As in mechanics a foot-pound is the unit of work and a foot-pound-second is the unit of power, so in electricity a volt-coulomb is the unit of electrical work, and a volt-coulomb-per-second, or a volt-ampère, is the unit of power. Consequently the product of the volt-coulombs by the seconds will represent the rate at which electrical power is expended.

But since the coulomb-per-second is equal to the ampère, the practical unit of electric power will be the volt-ampère, or the watt.

The volt-ampère or watt, the unit of electrical power, is equal to $\frac{1}{746}$ H. P.

Therefore, when the current strength in any circuit is known in ampères and the difference of potential is known in volts, the product of the two divided by 746 will give the horse power.

One watt=44.24 foot-second-pounds.

One watt=.7373 foot-minute-pound.

Since the electric power in watts is equal to the product of the volts by the ampères, the product $C\,E$ = the watts.

Now by Ohm's law we have $C = \frac{E}{R}$

or $C\,R = E$.

Substituting this value of E, in the expression $C\,E$ = the watts, we get :

$$C\,E = C \times C\,R = C^2\,R = \text{the watts.}$$

[illegible] the value [illegible] as equal to $\frac{E}{R}$ in the [illegible] = the watts, we have

$$[illegible] = [illegible] \times \frac{E}{R} = \frac{E^2}{R} = \text{the watts.}$$

We have therefore three expressions for the [illegible] of electric power, viz.,

(1.) [illegible] = the watts.

(2.) [illegible] = the watts.

(3.) $\frac{E^2}{R}$ = the watts.

(1.) [illegible] = the watts; or, the electric power is equal to the product of the quantity of electricity that passes per second, expressed in ampères, multiplied by the difference of electric potential, or level, through which it passes, expressed in volts.

(2.) $C^2 R$ = the watts; or, the electric power varies directly as the resistance R, when the current is constant, or as the square of the current, when the resistance is constant. If, for example, with a given resistance in circuit the power of the current that passes has a certain value, if this resistance remains the same and double the current be passed through the circuit, the electric power is four times as great, or is as the square of the current.

(3.) $\frac{E^2}{R}$ = the watts ; or, the electric power is inversely as the resistance R, when the electromotive force is constant, and is directly proportional to the square of the electromotive force, when the resistance is constant.

The heat activity, or the heat-per-second, produced by an electric current, is also proportional to the product $C E$, or the watts ; for, the heat is proportional to the square of the current strength in ampères multiplied by the resistance in ohms.

This fact is generally expressed as follows, viz:

Heat activity = $C^2 R t \times .24$, where t = the time in seconds, and .24 equals the amount of heat required to raise one gramme of water 1° C.

Work is done by electricity when a molecule is decomposed. This will be explained under the general head of electrolysis.

Work is also done by electricity when a current is passed through an electric motor, as will be explained under the head of electric motors.

Work is done when an electric current is sent through an uncharged storage battery so as to charge it.

Work is done when an electric current passes through an arc or incandescent lamp.

In all such cases the amount of work done or energy liberated can be measured by the product of the ampères by the volts; or, in other words, by the quantity of electricity which passes per second multiplied by the difference of potential through which it passes, *i. e.*, by the watts.

EXTRACTS FROM STANDARD WORKS.

J. A. Fleming, in his "Short Lectures to Electrical Artisans,"* on page 86, speaking of work and force, says:

If a body is acted upon by any force, and is displaced or moved in the opposite direction to that in which the force if allowed to act freely could move it, this is called making a displacement in opposition to a stress. Thus, for instance, if a weight is lifted, the motion is made to take place in opposition to the stress of gravity. Now, whenever this is the case, work is said to be done against the force, and the work is numerically measured by the product of the displacement and the mean stress estimated in the direction of the displacement. Energy is capacity for doing work, and when work is done, energy is said to be expended. Energy exists in many different forms. The energy of a bent spring is of a different form to that of a moving heavy body, and both of these are different to the form of energy represented by an electric current. Nevertheless, these forms of energy are found to be transmutable, and are capable of being exchanged for their equivalents in that form of energy expenditure represented by a definite mass lifted up to a certain height against gravity, or a displacement through a

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* "Short Lectures to Electrical Artisans; Being a Course of Experimental Lectures Delivered to a Practical Audience," by J. A. Fleming, M.A., D. Sc. London: E. & F. N. Spon. 1892. 210 pages, 74 illustrations. Price, $1.50.

certain distance made against a certain stress or force measured in dynes. Hence if feet and "pounds' weight" be our units of length and stress, one foot-pound or one pound mass lifted up one foot against gravity represents a certain quantity of work done and a certain amount of energy expended.

In the C. G. S. system a displacement of one centimetre against a force of one dyne is the unit of work, and is called one *erg*. Now since, as we have seen, the force of gravity acting on a mass of one gramme at London is 981 dynes, it follows that if a gramme is lifted up one centimetre, an amount of work equal to 981 ergs is done, and one foot-pound is equal to 1.356×10^7 ergs, or to 13,560,000 ergs. An amount of work equal to 10 million ergs is called one *joule*. Hence one foot-pound = 1.356 *joules*, or one *joule* = .7373 foot-pound. The elaborate researches of Mr. Joule, after whom this practical unit is called, have shown that the amount of heat required to raise one gramme of water one degree Centigrade in temperature is equal to 4.2 joules, or to 42 million ergs, or 3.096 foot-pounds. This number is called the mechanical equivalent of heat, and it represents the amount of work required to be done in order to increase the motion of the molecules of a gramme of water by an amount equivalent to heating that quantity of water one degree Centigrade.

The value which attaches as a work-doing agent to any energetic body, whether man, horse, steam-engine, or to any store of energy, is the rate at which such agent or store can deliver energy, or the work it can do per second. The work done per second by any agent is called its *activity* or power, and the unit of activity is a rate of working of one erg per second. As the rate is excessively small, the practical unit adopted is a multiple of this, equal to 10 million ergs per second and is called *one watt*. Common usage still retains as a unit of activity or power the horse-power, which is a rate of working of 550 foot-pounds per second, or 33,000 foot-pounds per minute. One horse-power is equal to 746 watts.

Ayrton, in his "Practical Electricity,"* on page 199, thus refers to the work done in an electric circuit:

If two conductors at different potentials be joined by a wire, electricity will flow from the one of higher potential to that of lower as long as any potential difference exists between them, exactly as, when a reservoir containing water at a higher level than the surrounding country has an opening made in the bottom of it, water will flow out of the reservoir from the higher to the lower level until all the water has fallen to the same level. *In order, therefore, to keep up a cons'ant electric current we must employ a machine that will transport electricity from a place of low to a place of high potential*, just as, to keep up a steady stream of water, we must have some machine or pump, or it may be the evaporating power of the sun, to keep raising the water from a low to a high level. With any such pump a certain portion of the power expended on it would be spent, not in actually raising water, but in overcoming the friction opposed by the channels inside the pump to the passage of the water, and the portion of the power so spent will be converted into heat, so that the work the water could do in falling would be less than that spent on the pump by the amount that had been wasted in heat in the pump. Consequently, the number of feet to which a pump could raise a pound of water would be less than the number of foot-pounds of work expended on the pump to raise the pound of water, and experiment shows that this difference would be greater the more quickly the pound of water was raised.

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* "**Practical** Electricity; A Laboratory and Lecture Course for **First Year** Students of Electrical Engineering," by W. E. Ayrton. **London**: Cassell & Company, Ltd. 1888. 516 pages, 180 illustrations. **Price**, $2.50.

Now a generator of an electric current, for example, a galvanic battery, a dynamo-electric machine, a magneto-electric machine, or a thermopile, is employed for the same sort of object as a pump, viz., to raise electricity from a low to a high potential, *in opposition* to the tendency the electricity apparently possesses to flow from a place of high to a place of low potential. The work the electricity so raised in potential can do per second, or per minute, in the external circuit, in the form of an electric current, may be partly done in turning an electromotor, or may be partly done in decomposing the substances in a voltameter, but in both cases a portion must be done in heating the external circuit, or the whole of the work may be done in merely heating the external circuit.

IX.—VARIETIES OF ELECTRIC CIRCUITS.

When more than a single electric source, or more than a single electro-receptive device, is placed in a circuit, the separate sources, or the separate electro-receptive devices, or both, are connected with such circuit in a variety of ways. Thus arise a variety of electric circuits.

Where more than a single electric source is employed, the separate sources are connected to one another in such a manner as to form a single source. Any arrangement of a number of separate electric sources, which permits them to act as a single source, is called a battery.

The most important of these different electric circuits are as follows :

(1.) The series circuits.
(2.) The multiple circuits.
(3.) The multiple-series circuits.
(4.) The series-multiple circuits.

In the series connection of electric sources, the positive pole of each separate source is connected to the negative pole of each succeeding source, and the plied by the difference of level through which it flows.

As in the case of the flow of a liquid, the amount of work done by the electric current is measured by the amount of electricity that passes, multiplied by the difference of potential under which it passes or flows.

Unit quantity of electric work is therefore equal to unit quantity of electricity multiplied by unit difference of potential.

The practical unit of electric quantity is called the coulomb. The practical unit of electric pressure, or difference of potential, is called the volt. It would follow, therefore, that the product of the coulombs by the volts will correctly represent the amount of work done by the passage or flow of a certain quantity of electricity.

The practical unit of electric work is called the joule, or the volt-coulomb. It is equal to the product of one coulomb by one volt.

In order to deduce the practical unit of electric power from the practical unit of electric work, it is only necessary to remember that power is equal to work-per-second. As in mechanics a foot-pound is the unit of work and a foot-pound-second is the unit of power, so in electricity a volt-coulomb is the unit of electrical work, and a volt-coulomb-per-second, or a volt-ampère, is the unit of power. Consequently the product of the volt-coulombs by the seconds will represent the rate at which electrical power is expended.

But since the coulomb-per-second is equal to the ampère, the practical unit of electric power will be the volt-ampère, or the watt.

The volt-ampère or watt, the unit of electrical power, is equal to $\frac{1}{746}$ H. P.

Therefore, when the current strength in any circuit is known in ampères and the difference of potential is known in volts, the product of the two divided by 746 will give the horse power.

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Since the electric power in watts is equal to the product of the volts by the ampères, the product $C\,E$ $=$ the watts.

Now by Ohm's law we have $C = \frac{E}{R}$

or $C\,R = E$.

Substituting this value of E, in the expression $C\,E$ $=$ the watts, we get :

$$CE = C \times C\,R = C^2\,R = \text{the watts.}$$

If we substitute the value C as equal to $\frac{E}{R}$ in the expression $C\,E =$ the watts, we have

$$C\,E = E \times \frac{E}{R} = \frac{E^2}{R} = \text{the watts.}$$

We have, therefore, three expressions for the value of the watts, or the units of electric power; viz.,

(1.) $C\,E =$ the watts.

(2.) $C^2\,R =$ the watts.

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* "Short Lectures to Electrical Artisans; Being a Course of Experimental Lectures Delivered to a Practical Audience," by J. A. Fleming, M.A., D. Sc. London: E. & F. N. Spon. 1892. 210 pages, 74 illustrations. Price, $1.50.

In the C. G. S. system a displacement of one centimetre against a force of one dyne is the unit of work, and is called one *erg*. Now since, as we have seen, the force of gravity acting on a mass of one gramme at London is 981 dynes, it follows that if a gramme is lifted up one centimetre, an amount of work equal to 981 ergs is done, and one foot-pound is equal to 1.356×10^7 ergs, or to 13,560,000 ergs. An amount of work equal to 10 million ergs is called one *joule*. Hence one foot-pound = 1.356 *joules*, or one *joule* = .7373 foot-pound. The elaborate researches of Mr. Joule, after whom this practical unit is called, have shown that the amount of heat required to raise one gramme of water one degree Centigrade in temperature is equal to 4.2 joules, or to 42 million ergs, or 3.096 foot-pounds. This number is called the mechanical equivalent of heat, and it represents the amount of work required to be done in order to increase the motion of the molecules of a gramme of water by an amount equivalent to heating that quantity of water one degree Centigrade.

The value which attaches as a work-doing agent to any energetic body, whether man, horse, steam-engine, or to any store of energy, is the rate at which such agent or store can deliver energy, or the work it can do per second. The work done per second by any agent is called its *activity* or power, and the unit of activity is a rate of working of one erg per second. As the rate is excessively small, the practical unit adopted is a multiple of this, equal to 10 million ergs per second and is called *one watt.* Common usage still retains as a unit of activity or power the horse-power, which is a rate of working of 550 foot-pounds per second, or 33,000 foot-pounds per minute. One horse-power is equal to 746 watts.

Ayrton, in his "Practical Electricity,"* on page 199, thus refers to the work done in an electric circuit:

> If two conductors at different potentials be joined by a wire, electricity will flow from the one of higher potential to that of lower as long as any potential difference exists between them, exactly as, when a reservoir containing water at a higher level than the surrounding country has an opening made in the bottom of it, water will flow out of the reservoir from the higher to the lower level until all the water has fallen to the same level. *In order, therefore, to keep up a cons'ant electric current we must employ a machine that will transport electricity from a place of low to a place of high potential,* just as, to keep up a steady stream of water, we must have some machine or pump, or it may be the evaporating power of the sun, to keep raising the water

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* "Practical Electricity; A Laboratory and Lecture Course for First Year Students of Electrical Engineering," by W. E. Ayrton. London: Cassell & Company, Ltd. 1888. 516 pages, 180 illustrations. Price, $2.50.

from a low to a high level. With any such pump a certain portion of the power expended on it would be spent, not in actually raising water, but in overcoming the friction opposed by the channels inside the pump to the passage of the water, and the portion of the power so spent will be converted into heat, so that the work the water could do in falling would be less than that spent on the pump by the amount that had been wasted in heat in the pump. Consequently, the number of feet to which a pump could raise a pound of water would be less than the number of foot-pounds of work expended on the pump to raise the pound of water, and experiment shows that this difference would be greater the more quickly the pound of water was raised.

Now a generator of an electric current, for example, a galvanic battery, a dynamo-electric machine, a magneto-electric machine, or a thermopile, is employed for the same sort of object as a pump, viz , to raise electricity from a low to a high potential, *in opposition* to the tendency the electricity apparently possesses to flow from a place of high to a place of low potential. The work the electricity so raised in potential can do per second, or per minute, in the external circuit, in the form of an electric current, may be partly done in turning an electromotor, or may be partly done in decomposing the substances in a voltameter, but in both cases a portion must be done in heating the external circuit, or the whole of the work may be done in merely heating the external circuit.

IX.—VARIETIES OF ELECTRIC CIRCUITS.

When more than a single electric source, or more than a single electro-receptive device, is placed in a circuit, the separate sources, or the separate electro-receptive devices, or both, are connected with such circuit in a variety of ways. Thus arise a variety of electric circuits.

Where more than a single electric source is employed, the separate sources are connected to one another in such a manner as to form a single source. Any arrangement of a number of separate electric sources, which permits them to act as a single source, is called a battery.

The most important of these different electric circuits are as follows :

(1.) The series circuits.
(2.) The multiple circuits.
(3.) The multiple-series circuits.
(4.) The series-multiple circuits.

In the series connection of electric sources, the positive pole of each separate source is connected to the negative pole of each succeeding source, and the negative and positive poles of the extreme ends are connected to the conductors of the circuit external to the battery.

Such a series connection of six voltaic cells is shown in Fig. 44. As will be seen from an inspection of this figure, the negative of pole No. 1 is connected with the positive pole of No. 2; the negative pole of No. 2 is connected to the positive pole of No. 3; the negative pole of No. 3 with the positive pole of No. 4, and so on through the series of cells; the positive pole of No. 1 and the negative pole of No. 6 being left free to form the poles of the battery.

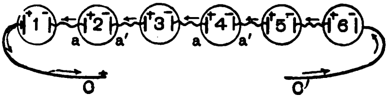


FIG. 44.—SERIES CONNECTION OF ELECTRIC SOURCES.

The series connection of sources will perhaps be better understood from an inspection of Fig. 45, where three voltaic cells, of the form known as the Leclanché cell, are connected together in series. In this form of voltaic cell the zinc plate forms the negative pole, and the carbon plate the positive pole. It will be seen from the drawing that the carbon of the first cell on the left, is connected to the zinc of the second cell, the carbon of the second cell is connected to the zinc of the third cell, while the zinc of the first cell and the carbon of the last cell form the poles of the battery.

In the case of the series connection of sources, the electromotive force of the single source or battery so obtained is equal to the sum of the electromotive forces of the separate cells. For example, if the electromotive force of a single Leclanché cell be that of the average cell of this character, namely, 1.47 volts, the electromotive force of the series-connected battery of three cells, as shown in Fig. 45, is equal to 3 × 1.47 or 4.41 volts.

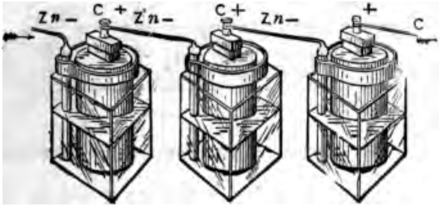


FIG. 45.—BATTERY OF THREE SERIES-CONNECTED LECLANCHÉ CELLS.

The resistance of such a series connection is equal to the sum of the resistances of all the separate cells.

This follows from the fact that the resistance of a conductor increases directly in proportion to its length. The resistance of a voltaic cell arises mainly from the resistance of the liquid in which the metallic plates are dipped. If a column of liquid of a certain length possess a certain resistance, an increase in its length of, say, three times, must of course produce an increase in its resistance of three times what it originally was.

The same is true when electro-receptive devices are placed in a circuit in series. The resistance of the circuit will be increased in proportion to the number of electro-receptive devices added.

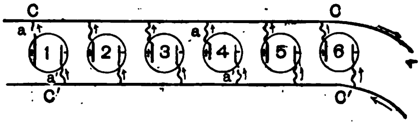


FIG. 46.—MULTIPLE-ARC CONNECTION OF SOURCES.

If, for example, the resistance of a single arc lamp be four ohms, the resistance of thirty such lamps placed in a circuit in series will be 120 ohms.

In the connection of electric sources in multiple circuits, or, as this connection is sometimes called, in multiple-arc circuits or in parallel, all the positive terminals or poles of the separate sources are connected to a single positive lead or conductor, and all the negative terminals or poles are similarly connected to a single negative lead or conductor.

In Fig. 46 a multiple connection of six voltaic cells is shown.

Here the positive poles of all the cells are connected to a single positive lead, or conductor, *C C*, and the negative poles of all the cells are similarly connected to the single negative lead, or conductor, C' C'.

The multiple connection of cells will perhaps be better understood from an inspection of Fig. 47, in which three Bunsen cells are connected together in multiple-arc.

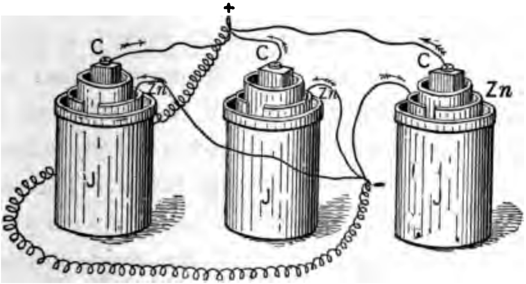


Fig. 47.—Battery of Three Multiple-Arc Connected Bunsen Cells.

All the positive or carbon poles are connected together, and to a single positive lead, and all the negative or zinc poles are similarly connected together to a single negative lead.

In the case of electric sources the effect of the multiple connection is to decrease the resistance of the battery in the direct proportion of the number of separate cells so joined.

That such must be the case will be seen from the following considerations: The resistance of a conductor decreases as the area of cross section of the conductor increases; for, as we have seen, a steady electric current passes through the mass of the conductor. The greater, therefore, the area of cross section of a conductor, the greater its mass, and, consequently, the smaller its resistance.

Now, when the three voltaic cells are connected in multiple as shown in Fig 47, there is so produced an increase in the area of cross section of the liquid mass, directly between the plates, and, therefore, there must be produced a corresponding decrease in the resistance of such liquid. The current strength must necessarily increase in such a circuit in the same proportion as the resistance of the circuit decreases.

There is, however, no increase produced in the electric level; that is, in the electromotive force, since each cell has its electric level placed in the same level as that of the cell to which it is connected.

In the series connection of electric sources the electromotive force of the battery so obtained is increased, while in the multiple connection of sources the strength of the current passing is increased.

In the multiple-series connection of electric sources a number of separate cells are joined or connected in separate groups in series, and these separate groups are subsequently connected in multiple.

A multiple-series connection of six voltaic cells is shown in Fig. 48. Here three separate groups of two cells each are connected in series, and these separate groups are joined as shown, in multiple circuit, to leads or conductors *C C'*.

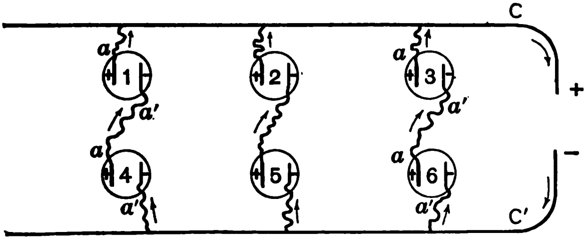


FIG. 48.—MULTIPLE-SERIES CONNECTION OF SOURCES.

The electromotive force of a multiple-series circuit is increased in proportion to the number of cells in any separate series-connected group. At the same time the electric resistance is decreased in proportion to the number of such groups that are subsequently connected in parallel. Thus in the battery shown in Fig. 48, the electromotive force of the battery is twice as great as the electromotive force of any single cell, but the resistance of the battery is twice the resistance of a single cell divided by three, the number of groups connected in parallel.

Or, using the terms of Ohm's law; if we call r, the resistance of any single source, and E, the electromotive force of a single source, then C, the current strength of such a battery, is

$$C = \frac{2\,E}{\frac{2\,r}{3}}.$$

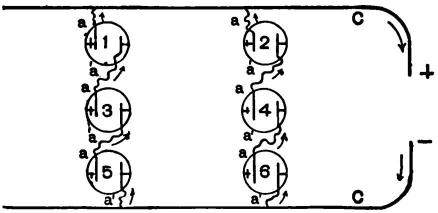


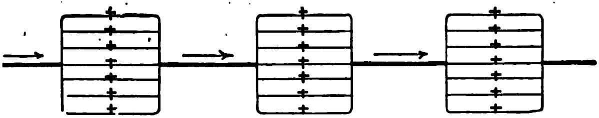
Fig. 49.—Multiple-Series Connection of Sources.

In Fig. 49 a multiple-series connection of six cells is shown, in which two series groups of three cells each are subsequently joined in multiple to the leads C C'.

In the series-multiple connection a number of separate electric sources are connected in multiple, and these separate groups are subsequently joined to one another in series. Such a connection is shown in Fig. 50.

This connection is generally limited to the con- ction of electro-receptive devices. The resistance each multiple group is equal to the resistance of a igle branch divided by the number of branches.

Some difference of usage exists as regards the eaning attached to the terms multiple-series and ries-multiple. By some these terms are reversed. ius the connection shown in Fig. 50 is called by



G. 50.—SERIES-MULTIPLE CONNECTION OF ELECTRIC SOURCES.

me multiple-series connection, while those shown in gs. 48 and 49, are called series-multiple connec- ns. If, however, it be remembered that Figs. 48 d 49 represent a multiple of series-connected arces, it would appear that the term for the con- ction here shown should be multiple-series; and, at Fig. 50 represents a series of multiple connec- ns, and should therefore be called a series-multiple nnection.

When an additional circuit or path is provided for electric current, the current branches or divides, ie part flowing through the new path and the lance flowing through the old circuit. Such an lditional circuit is called a shunt or derived circuit.

Thus in Fig. 51 is shown a voltaic battery *B*, connected in circuit with a form of electro-receptive device *G*, called a galvanometer. If now an additional circuit or path, *S*, be provided, placed as shown in the figure, a part of the current will flow through the circuit *S*, which is called the derived or shunt circuit. The current from the battery *B*, coming out of its positive pole, situated say at the right hand, passes through the circuit, and when it meets the point where the additional circuit *S* joins it on the right of the figure, divides, part of the current flowing through the new path *S*, and the balance flowing through the galvanometer *G*. Then the branches of the current again unite to form a single branch at the point on the left of the figure where *S* joins the circuit.

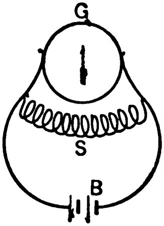


FIG. 51.—SHUNT OR DERIVED CIRCUIT.

Knowing the resistance of any number of branch circuits, the proportion of current flowing through each branch can be readily calculated.

EXTRACTS FROM STANDARD WORKS.

Slingo and Brooker, in their "Electrical Engineering for Electric Light Artisans and Students,"* speaking of circuits, say on page 25:

When two or more wires are joined together so that the current divides between them, they are said to be joined up in "parallel," and when the end of one is joined to the end of another so that the whole current goes through both wires, one after the other, the wires are said to be joined up in "series."

The law for double channels holds equally good for multiple channels. Thus, if there are ten wires of uniform resistance and a current of ten ampères divides between them, it will do so equally, so that one ampère will flow through each wire. When the resistances vary, then the current flowing through each wire will vary also, but in inverse ratio.

When, however, two or more wires are joined up in parallel, a serious alteration is made in the condition of the circuit, for the total amount of current that is produced, whether it be from a primary battery, a dynamo-electric machine, or any other source of electrical energy, will be increased. This increase follows from the fact that when wires are joined up in parallel, their united or, technically speaking, their joint resistance is less than that of any one of the wires taken separately. The meaning of this will be more readily apparent if a wire is regarded as a conductor rather than as a source of resistance. Thus, if two equal wires lie side by side, and the current is allowed to flow through them, the conducting power of the double wire will be twice that of either wire taken separately, in precisely the same way that a water or gas pipe two square inches in section will transmit twice as much as a similar pipe only one square inch in section. If, therefore, the conductivity of the two wires in parallel is twice that of one of them, their united or joint resistance will be only half that of one of them. Thus, if two wires, each of 100 ohms resistance, are joined to a battery in parallel, their joint resistance will be 50 ohms.

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* "Electrical Engineering for Electric Light Artisans and Students," by W. Slingo and A. Brooker. London: Longmans, Green & Co. 1891. 631 pages, 307 illustrations. Price, $3.50.

X.—MAGNETISM.

There exists in nature an ore of iron called magnetite, some specimens of which possess the curious property of attracting iron filings. Such specimens of iron ore were known to the ancients, and were named by them lodestones, because, if suspended by a thread or floated on water, so as to be free to move, they came to rest with a certain part of the stone pointing approximately to the north star, or to the earth's geographical north.

A lodestone owes its property of attracting iron filings, or of pointing to the north, to the magnetism it possesses. It is a natural magnet.

If a lodestone be rolled in iron filings, the filings will be attracted to the stone in much greater quantity at two points than elsewhere. These points are called the poles of the lodestone or magnet.

If a lodestone or natural magnet be floated on a water surface, as, for example, by placing it on a board, it will be attracted or repelled by another lodestone held near it.

If a bar of hardened steel shaped as shown in

Fig. 52, be stroked by the poles of a lodestone, it will acquire all the properties of the lodestone, or will become a magnet.

The needle has become magnetized by the act of rubbing against the lodestone. If such a magnetic needle be supported at its centre of gravity on a vertical axis, so as to be free to move in a horizontal plane, it will come to rest with its N pole pointing approximately to the earth's geographical north. Such a magnet is known technically as a magnetic needle.

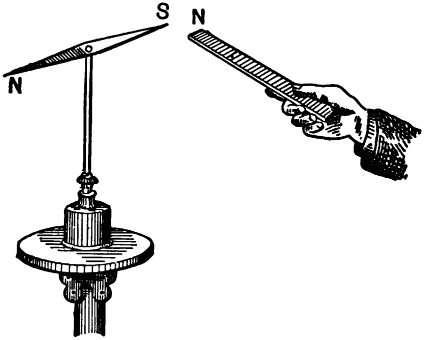

FIG. 52.—MAGNETIC ATTRACTION AND REPULSION.

The pole of the magnetic needle which points to the earth's geographical north is called the north or the N pole of the needle. The pole which points to the earth's geographical south is called the south or the S pole of the needle.

The north pole of a magnetic needle when held near the north pole of a readily movable magnetic needle, such, for example, as that shown in Fig. 52, will repel the needle; if, however, its north pole be held near the south pole of the needle, it will attract it.

The laws of magnetic attraction and repulsion may be expressed as follows:

(1.) Like magnetic poles repel each other; that is, a north magnetic pole repels another north magnetic pole, or a south magnetic pole repels another south magnetic pole.

(2.) Unlike magnetic poles attract each other; that is, a north magnetic pole attracts a south magnetic pole, while a south magnetic pole attracts a north magnetic pole; or, in other words, the attraction is mutual.

(3.) The force of magnetic attraction or repulsion is in proportion to the product of the strength of the magnetism possessed by the two magnets, and in the inverse proportion to the square of the distance between the poles. It will be seen that these laws are like the laws of attraction and repulsion of electric charges. The law of inverse squares, as applied to magnets as generally constructed, is true of points only, not of surfaces.

Magnetic attractions and repulsions can be shown by floating a small magnet on the surface of water as represented in Fig. 53. If the north pole of another magnet be held near the north pole of the floating magnet the latter will be repelled. If, on the contrary, the south pole of another magnet be held near its north pole, the floating magnet will be attracted.

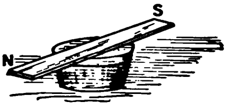

FIG. 53.—FLOATING MAGNET.

Various shapes are given to magnets. The commonest of these is the straight bar and the horseshoe. The name horseshoe magnet is given to such a magnet from its resemblance in shape to an ordinary horseshoe. This magnet is sometimes called a U-shaped magnet.

In order to readily increase the strength of a magnet, several separate magnets are so placed together as to act as a single magnet. Such a combination is known as a compound magnet or magnetic battery.

The poles of a straight bar magnet that has been properly magnetized are situated at or near the ends of the bar. If such a magnet be rolled in iron filings, the amount of filings attracted will be greater near the poles, and will decrease toward the middle of the bar, or toward a line called the equator of the magnet.

A compound bar magnet is shown in Fig. 54. It consists of several separate bar magnets placed together with their similar poles facing one another. A compound bar magnet is much stronger than a single bar magnet of the same area of cross section, because the separate bars can be much more strongly magnetized than could a single bar.

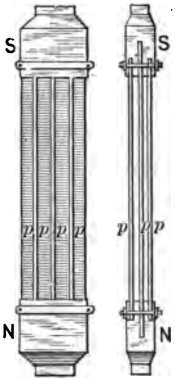

FIG. 54.—COMPOUND BAR MAGNET.

Soft iron and steel differ very greatly in the ease with which they are magnetized. They also differ in the ease with which they lose their magnetism or are demagnetized. Hardened steel acquires magnetism with considerable difficulty ; it also loses magnetism with considerable difficulty. Soft iron, on the contrary, both acquires and loses its magnetism very readily. Even soft iron, however, retains a small amount of magnetism after being magnetized. This is called residual magnetism.

The power with which a substance resists magnetization or demagnetization is called its coercive power. The ability of a substance to retain its magnetism, after it is once magnetized, is called its magnetic retentivity.

Magnets made from hardened steel are called permanent magnets, because they retain their magnetism for an almost indefinite time after being magnetized; in other words, the magnetic retentivity of hardened steel is very great.

Every magnet possesses an atmosphere of influence surrounding its poles, called the field of the magnet. The properties of the magnetic field are due to the space occupied by the field being crossed or traversed by certain lines called lines of magnetic force.

The number of lines of magnetic force which pass through a given area of cross section is not equal at all parts of the magnetic field, but is greater in some places than in others; that is, the magnetic density varies in different parts of the field.

Lines of magnetic force form closed circuits, a part of their path being through the air or other medium surrounding the magnet. The lines are assumed to come out of a magnet at its north pole, and, after having passed through the space outside the magnet, to re-enter it at its south pole. It will be noticed that this convention is similar to that employed in the case of electric sources, where the electricity is assumed to come out of a source at its north pole, and, after having passed through the circuit with which the source is connected, to re-enter it at its south pole.

In order to show the direction which the lines of magnetic force take in the space situated near the poles of a magnet, a sheet of paper may be placed in a horizontal position over the magnet, and iron filings sprinkled over the paper. If, now, the paper be gently tapped, so as to permit the filings to readily arrange themselves, they will assume the positions taken by the lines of magnetic force.

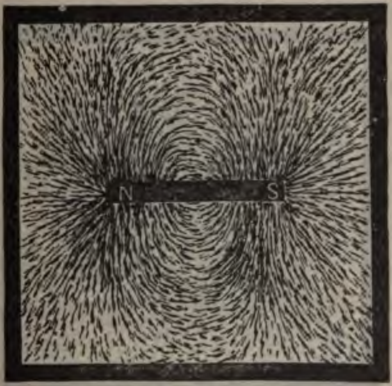

FIG. 55.—MAGNETIC FIELD.

Such a figure may be regarded as representing that portion of the magnetic field that is situated in the plane of the paper.

In Fig. 55 is shown a part of the magnetic field of a straight bar magnet *N S*, lying in a horizontal plane parallel to its length.

It will be noticed from an inspection of the figure that the filings have accumulated in greater quantity near the poles of the magnet. If a single pole be placed directly under the sheet of paper, sprinkling iron filings over it will result in the production of the magnetic field shown in Fig. 56.

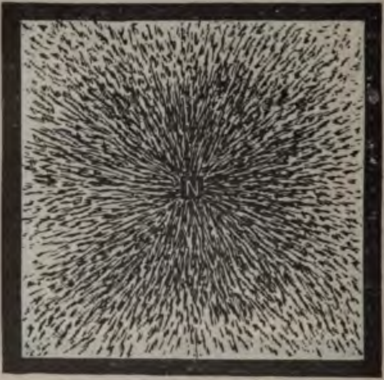

FIG. 56.—MAGNETIC FIELD.

A careful inspection of these figures will show :

(1.) That like magnetic poles repel each other. This may be seen by observing the radiation of the lines in the immediate neighborhood of the magnet poles. The divergence of the lines shows repulsion.

(2.) That unlike magnetic poles attract each other. This is shown by the joining of the lines of polarized particles of iron filings that lie in the path of the lines which come out the north pole with those that pass into the south pole. These chains form closed circuits around the poles, a portion of the circuit being completed through the iron of the magnet.

The magnetic field may be permanently fixed by obtaining the groupings of iron filings on the wax-covered surface of a glass plate that is subsequently heated. These wax-fastened filings may be used for obtaining photographically printed negatives; or, true photographic negatives may be obtained by placing the filings on the sensitized surface of a photographic plate, in the darkened photographic room, and, then exposing the plate for a few seconds to the light, afterward developing.

Since lines of magnetic force come out of a magnet at one place or pole, and re-enter it at another place or pole, all magnets must necessarily possess two poles, and can have but two poles. Under some circumstances, however, magnets appear to possess more than two poles. If, for example, the magnet shown in Fig. 57 be rolled in iron filings, the filings will collect in greater quantity at the points *A*, *B*, *C*, as shown. Here it appears as if the magnet possessed only three poles. In reality, however, such a magnet consists of two separate magnets, *A B* and *B C*, whose two similar —, —, are poles placed together as shown. Such a magnet is called an anomalous magnet.

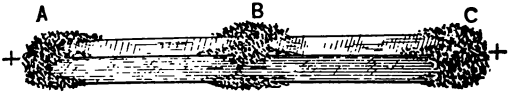

FIG. 57.—ANOMALOUS MAGNET WITH APPARENTLY THREE POLES ONLY.

In Fig. 58 is shown an anomalous magnet with apparently four poles. It actually consists of three separate magnets, *AB, BC* and *CD*, with their similar poles —, —, and +, +, placed together.

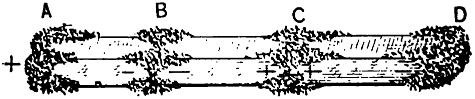

FIG. 58.—ANOMALOUS MAGNET WITH APPARENTLY FOUR POLES ONLY.

A curious form of anomalous magnet is obtained by touching the centre of a star-shaped plate of hardened steel by one of the poles of a magnet. The part touched becomes of opposite polarity to the touching pole, and the points of the star of the same polarity. This would make, in the case of a five-pointed star, a magnet with apparently six poles. It consists, however, in reality of five separate magnets, five similar poles of which occupy the points of the star, the five remaining similar poles being massed at the centre, where they form, apparently, a single pole.

Different specimens of steel differ greatly in their ability to become magnetized and to retain such magnetization. As a rule, a very hard steel retains magnetism best. Various methods are adopted for hardening the steel. They consist, generally, in suddenly cooling the metal while highly heated.

Various processes are employed for producing magnetism in hardened steel. We will here describe one of these methods only; namely, the method of magnetization by touch. This includes three different varieties:

(1.) The method of single touch.

(2.) The method of separate touch.

(3.) The method of double touch.

In the method of single touch, the bar to be magnetized is touched or rubbed with one pole of the magnetizing magnet. The magnetizing magnet is drawn over the surface of the bar to be magnetized from end to end, and returned through the air, the stroke being repeated a number of times. This method is shown in Fig. 59.

The lower bar is here represented as being magnetized by the upper bar, which has been drawn from right to left, as indicated by the arrow. The —, or south polarity, indicated at the right hand, appears when the magnetizing magnet approaches the extreme left of the magnetized magnet.

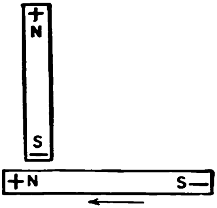

FIG. 59.—MAGNETIZATION BY SINGLE TOUCH.

In the method of separate touch, two magnetizing bars are placed as shown in Fig. 60 at the middle of the bar to be magnetized, with their opposite poles near each other, but not touching, and are drawn away from each other toward the end of the bar. This motion is repeated a number of times, the magnets being each time returned to the middle of the bar through the air.

This method of magnetization is especially suited for obtaining a uniform magnetization, so that in the case of a straight bar or needle, the poles will be situated exactly at the ends of the bar. It is, therefore, especially suited for the magnetization of magnetic needles.

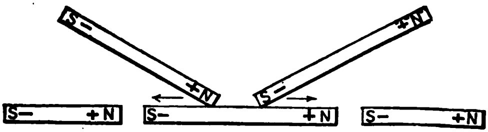

FIG. 60.—MAGNETIZATION BY SEPARATE TOUCH.

In the method of double touch, two magnets are placed with their opposite poles together at the middle of the bar that is to be magnetized, as shown in Fig. 61, and are then moved to the end of the bar, when, instead of lifting them from the magnet to pass them through the air to the other end, they are moved over the surface of the bar to the other end, and these to-and-fro motions are repeated a number of times. The motion is stopped in the middle of the bar, when the magnetizing magnets are moving in opposite direction from that in which they were moved when first started. This method of magnetization

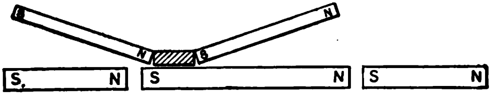

FIG. 61.—MAGNETIZATION BY DOUBLE TOUCH.

produces fairly powerful magnets, but, unless great care is taken, the distribution of the magnetism will be very irregular.

A horseshoe magnet may be employed, in the manner shown in Fig. 62, to magnetize a number of separate bars by a modification of the method of double touch. Here the four bars that are to be magnetized are placed in the form of a hollow rectangle, the angular spaces where the ends of the magnets touch being filled with bars of soft iron. The magnetizing horseshoe magnet is then moved around the circuit several times in the same direction.

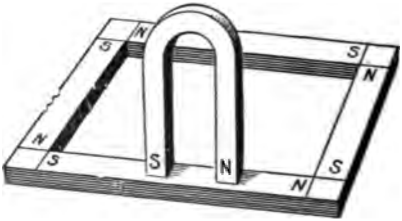

FIG. 62.—MAGNETIZATION BY DOUBLE TOUCH.

The most convenient method of producing magnetism is by means of electric currents. This method will be explained in connection with electromagnets.

EXTRACTS FROM STANDARD WORKS.

Lloyd, in his "Treatise on Magnetism,"* page 1, speaks thus of the general phenomena of this strange force:

> Magnetism is the property, commonly supposed to be peculiar to certain substances, of attracting iron. It was first observed in a certain ore of iron, thence called *magnetic iron ore.* This mineral—the lodestone of the ancients—is composed of the peroxide and protoxide of iron, in combination with a small quantity of earthy substances. It is of a dark gray color; and the fresh fracture possesses a metallic lustre. It is found in many parts of the globe in connection with other iron ores; but is particularly abundant in the iron mines of Sweden and Norway. When a piece of this substance is brought near to small fragments of iron it attracts them, and this attraction is observed to be concentrated in certain points of the mass, thence called *poles.* Thus when a lodestone is brought close to a mass of iron filings, the latter are immediately attracted and made to adhere, and the adhering particles are accumulated round certain parts of the surface of the mineral, leaving the remainder nearly free.
>
> Steel may be made to acquire artificially the properties which naturally belong to the lodestone. Thus, if a straight

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* "A Treatise on Magnetism, General and Terrestrial," by Humphrey Lloyd, D.D., D.C.L. London: Longmans, Green & Co. 1874. 239 pages. Price, $3.75.

bar of steel be rubbed in the direction of its length with one of the poles of the lodestone—care being taken to make it pass always in the same direction—the steel bar acquires the properties which were inherent in the lodestone; it becomes magnetic, and attracts iron in its vicinity. The same property may be communicated to the steel bar without the aid of the natural lodestone, by striking it on the end with a hammer, when held in a vertical position. The poles or centres of attraction of such a bar are situated close to its extremities. The middle of the bar is without action, and the section passing through it is called the *neutral section.*

Conversely, iron reacts upon and attracts the magnet with an equal force. This may be shown by holding a piece of iron near the pole of a magnet; if the latter be free to move, it will approach the former, until it finally adheres to it by one of its poles. When the two bodies—the magnet and the iron—are both free to move, they will approach one another until they meet, the spaces described by each being inversely as their masses. These effects take place without any diminution of action when any body, which is not itself magnetic, is interposed between the magnet and the iron.

Nickel and *cobalt* are acted on by the magnet and react upon it, in the same manner as *iron*, although in a less degree, and are thence classed along with it as magnetic bodies. We shall hereafter see that this class of substances is unlimited.

XI.—MAGNETIC INDUCTION.

When a body is magnetized by stroking it with another magnet, the polarity produced will depend on the polarity of the magnetic pole with which it was stroked. If, for example, the north pole of a magnet be touched to a piece of hardened steel, it will produce a south pole where it touches the steel. If, however, the steel be touched by the south pole of the magnet, the point touched will become a north pole. In other words, the point of the magnetizable substance touched or stroked by a magnet will always acquire a polarity opposite to that of the touching or magnetizing pole.

The correctness of the above principles can be shown by the following simple experiment. Before touching the bar that is to be magnetized, ascertain the polarity of the touching pole by noticing whether it attracts or repels the north pole of a readily moving magnetic needle. Let us suppose that it repels the north pole, and that, therefore, its polarity is north. If, now, this north pole be touched to a bar of hardened steel, it will produce south polarity at the point where it touches. In the same way it can be shown

that the polarity produced by touching a bar of steel by a south pole will be a north pole.

It is not necessary that the magnetizing pole actually touch the body it is to magnetize. If it merely be brought near to the bar that is to be magnetized, but not in actual contact with it, the bar will still be magnetized with a polarity opposite to that of the magnetizing magnet.

The production of magnetism in this way, by bringing the magnetizing pole near to the substance, but not actually in contact with it, is known as magnetic induction.

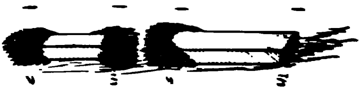

FIG. 53.—MAGNETIC INDUCTION.

Suppose, for example, that the magnet N' S', shown in Fig. 53, be brought near to, but not actually touching, one end of the unmagnetized bar N S. Under these circumstances a south pole will be produced in the bar at the point S, which lies nearest to the magnetizing pole N', and, at the same time, a north pole N, will be produced at its furthest end. In order to show the position of these poles, iron filings have been sprinkled over the bar N S, and over one of the poles N', of the magnetizing bar, as shown.

The manner in which magnetism is produced by induction from another magnet can be best explained by the action of the lines of magnetic force. It will be remembered that every magnet possesses lines of magnetic force passing through and producing what is called a magnetic field, in the space which lies outside of the body of the magnet. These lines of force, as we have already seen, are assumed to come out of a magnet at its north pole, and to re-enter it at its south pole, completing the path of the circuit by passing through the mass of the magnet itself. A complete circuit is formed by the lines of magnetic force, and, as in the case of an electric circuit, part of the path is situated outside the source and the remainder of the path lies within the source.

A magnetic circuit possesses a true resistance to the passage of lines of magnetic force, called the magnetic resistance. Different media differ in the ease with which they are permeated by lines of magnetic force, or in the ease with which the lines of force pass through them. This is sometimes called their magnetic permeability.

The air which surrounds the magnet offers a much greater resistance to the passage of lines of magnetic force, or possesses a smaller permeability,

that the polarity produced by touching a bar of steel by a south pole will be a north pole.

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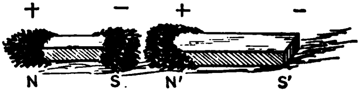

FIG. 63.—MAGNETIC INDUCTION.

Suppose, for example, that the magnet *N′ S′*, shown in Fig. 63, be brought near to, but not actually touching, one end of the unmagnetized bar *N S*. Under these circumstances a south pole will be produced in the bar at the point *S*, which lies nearest to the magnetizing pole *N′*, and, at the same time, a north pole *N*, will be produced at its furthest end. In order to show the position of these poles, iron filings have been sprinkled over the bar *N S*, and over one of the poles *N′*, of the magnetizing bar, as shown.

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than the steel of which the magnet is formed. The steel appears to possess the power of concentrating the lines of force upon it. Consequently, in the mass of the steel, these lines are close together, while in the air or space outside the magnet they are spread through a much larger space.

But since lines of magnetic force form closed circuits, the same number of lines pass through the body of the magnet as through the air or space outside the magnet. There must, therefore, be a greater number of lines of magnetic force in a given area of cross section of the magnet than in an equal area of cross section of the space outside the magnet. Or, in other words, there is a greater magnetic density in the magnet than there is in the air outside of the magnet.

Although in an ordinary magnet lines of magnetic force pass partly through the air and partly through the magnet, yet in some cases they pass entirely through iron and steel.

When the magnetic circuit is completed entirely through iron or steel, it is called a closed magnetic circuit. When it is completed partly through iron and partly through air, it is called a divided magnetic circuit. Such circuits are shown in the complete and divided rings in Figs. 64 and 65 respectively.

When a magnetizable body is brought into a magnetic field, the following phenomena occur :

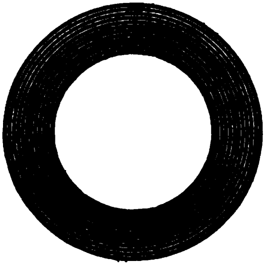

FIG. 64.—CLOSED MAGNETIC CIRCUIT.

(1.) The lines of magnetic force pass through the body and are concentrated around it.

If a magnetizable body, shaped and supported like a magnetic needle, is able to move freely in a horizontal plane, but is not able to move forward bodily, it will come to rest with its greatest length in the direction

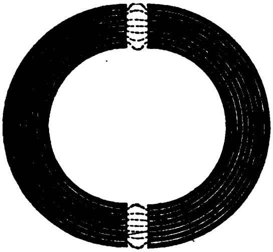

FIG. 65.—DIVIDED MAGNETIC CIRCUIT.

of the lines of force, because this direction offers the least resistance to the circuit of the lines of magnetic force.

(2.) The magnetizable body will become magnetic, its south pole being situated where the lines of force of the magnetizing field enter it, and its north pole where these lines of force come out of it.

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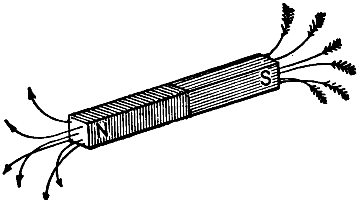

FIG. 66.—DIRECTION OF LINES OF FORCE.

Since the lines of magnetic force come out of the north pole of this magnet, as shown conventionally by the curved arrows, they must enter the piece of iron at that end which is nearest the north pole and will, therefore, produce in it a south polarity at this end.

On entering the piece of iron, they pass through it, and coming out at its furthest end produce a north pole at that end. If, now, Fig. 63 be again inspected, it will be understood why the end *S*, which lies nearest to the magnetizing pole *N'*, acquires a south polarity, and the end *N*, which lies furthest from it, acquires a north polarity.

As already mentioned, the lines of magnetic force form closed circuits.

Like an electric circuit, a magnetic circuit consists of three distinct parts; namely,

(1.) The source or place where the lines of magnetic force are originated.

(2.) The various media which form conducting paths for the lines of magnetic force.

(3.) The various magneto-receptive devices, consisting generally either of magnetizable materials placed so as to be traversed by the lines of force and energized by their passage through them, with the consequent production of magnetism therein; or, of conductors, which, as will be afterward explained, have differences of potential generated in them by the passage of lines of force through them.

When a magnetizable substance undergoes magnetic induction by being placed in a magnetic field, then—

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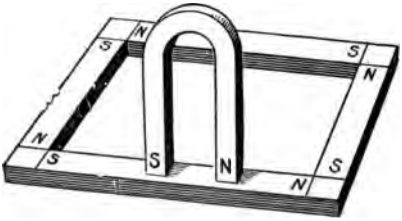

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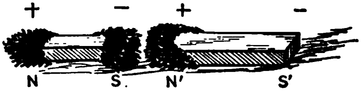

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A magnetic circuit possesses a true resistance to the passage of lines of magnetic force, called the magnetic resistance. Different media differ in the ease with which they are permeated by lines of magnetic force, or in the ease with which the lines of force pass through them. This is sometimes called their magnetic permeability.

The air which surrounds the magnet offers a much greater resistance to the passage of lines of magnetic force, or possesses a smaller permeability,

than the steel of which the magnet is formed. The steel appears to possess the power of concentrating the lines of force upon it. Consequently, in the mass of the steel, these lines are close together, while in the air or space outside the magnet they are spread through a much larger space.

But since lines of magnetic force form closed circuits, the same number of lines pass through the body of the magnet as through the air or space outside the magnet. There must, therefore, be a greater number of lines of magnetic force in a given area of cross section of the magnet than in an equal area of cross section of the space outside the magnet. Or, in other words, there is a greater magnetic density in the magnet than there is in the air outside of the magnet.

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When a magnetizable body is brought into a magnetic field, the following phenomena occur :

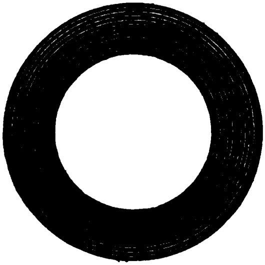

Fig. 64.—Closed Magnetic Circuit.

(1.) The lines of magnetic force pass through the body and are concentrated around it.

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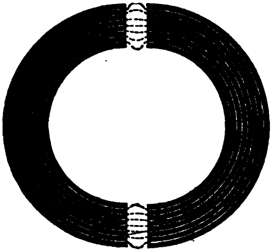

Fig. 65.—Divided Magnetic Circuit.

of the lines of force, because this direction offers the least resistance to the circuit of the lines of magnetic force.

(2.) The magnetizable body will become magnetic, its south pole being situated where the lines of force of the magnetizing field enter it, and its north pole where these lines of force come out of it.

It will now be seen why a body brought into the north field of a magnet acquires south polarity at that end which is nearest the north magnetizing pole. Suppose, for example, that a piece of iron is brought into the north field of the magnet shown in Fig. 66.

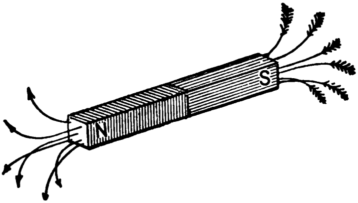

FIG. 66.—DIRECTION OF LINES OF FORCE.

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When a magnetizable substance undergoes magnetic induction by being placed in a magnetic field, then—

(1.) The character of the magnetic polarity produced will depend on the direction in which the lines of magnetic force pass through the magnetizable substance;

(2.) The points or places where the poles are produced will depend on the points or places where the lines of force enter and pass out from the magnetizable substance;

(3.) The strength of this magnetization will depend on the number of lines of force which pass through the magnetizable substance.

Since the lines of magnetic force, per given area of cross section, are more numerous in the space lying outside the magnet, near its poles than elsewhere, the nearer the magnetic poles are brought to a magnetizable substance, the greater will be the number of lines of force that pass through it, and hence the stronger will be the magnetization produced by induction.

In the same way, the greater the strength of the magnetizing magnet, or the greater the number of lines of force which pass through its field, the stronger will be the magnetization produced by induction.

The strength of magnetization produced also depends on what is called the magnetic susceptibility, or on the relation which exists between the strength or intensity of the magnetizing field and the intensity of the magnetism produced.

It will now be understood why the polarity produced by rubbing or stroking a magnetizable substance by a magnetic pole is the same as that produced by merely bringing it near to that pole; for, in such cases, just as much as when the body is rubbed by the magnet pole, the lines of force of such pole pass through the body and so produce magnetism in it.

The groupings of iron filings in the form shown in Figs. 55 and 56 of a former Primer, on the sheets of paper placed over a bar magnet in planes respectively parallel to its length and at right angles to its length, afford excellent examples of the production of magnetism by induction. The iron filings, under the gentle tapping given to the paper, arrange themselves in the directions of the lines of force which thread through them. Each particle becomes a minute magnet with its south pole where the lines enter it and its north pole where they leave it. Magnetic figures, therefore, consist of lines of magnetized particles.

The action of a mass of soft iron placed near the poles of a magnet, and called an armature, will now be understood. Suppose, for example, that a piece of soft iron, shaped as shown at *A*, in Fig. 67, be brought into contact with the poles *N*, *S*, of the compound horseshoe magnet; since soft iron permits the lines of magnetic force to pass readily through it, the armature will concentrate these lines on itself and will thereby be attracted to the magnet.

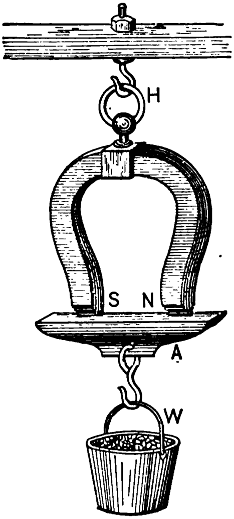

FIG. 67.—ARMATURE OF MAGNET.

A magnet so armed possesses a greater power of holding weights, or, as it is called, a greater portative power, than it otherwise would. The weight *W*, which the horseshoe magnet shown in Fig. 67 is able to carry, is much greater than when it is not provided with a suitable armature. The portative power depends both on the shape of the magnet and on the shape of its armature, as well as on the strength of the magnet poles.

When a magnet is not provided with a suitable armature, many of the lines of magnetic force are diffused from its poles, and spread through the space around them, so that only some of them act on a body brought near the poles. This useless dissipation of some of the lines of magnetic force is called magnetic leakage.

Substances differ very markedly in the manner in which they act on the lines of force when brought into a magnetic field. Some, like iron and steel, concentrate the lines upon them; others, like bismuth and antimony, appear to diffuse the lines of force, or to apparently repel them.

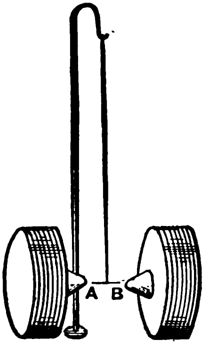

FIG. 68.—BEHAVIOR OF PARAMAGNETIC SUBSTANCE.

Substances which like iron or steel appear to concentrate the lines of force upon them are called paramagnetic substances. Nickel, cobalt, chromium, cerium and manganese are paramagnetic substances.

Substances which when brought into a magnetic field appear to diffuse the lines of magnetic force are called diamagnetic substances. Bismuth, phosphorus, zinc and mercury are diamagnetic substances.

A paramagnetic substance, cut in the form of a long cylinder or bar and suspended between the poles of a powerful magnet, as shown in Fig. 68, will come to rest with its greatest dimensions in the line of the poles.

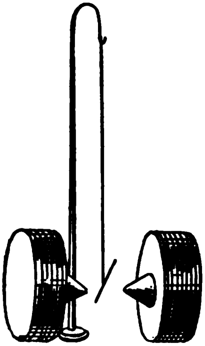

FIG. 69.—BEHAVIOR OF DIAMAGNETIC SUBSTANCE.

A diamagnetic substance, cut in the form of a cylinder or bar and suspended between the poles of a powerful magnet, will come to rest with its least dimensions in the line of the poles, as shown in Fig. 69.

In this latter case the diamagnetic substance acts as if it were repelled by the magnet poles instead of being attracted by them like a paramagnetic substance. Tyndall believes that the polarity possessed by a diamagnetic substance is distinct and different from the polarity possessed by an ordinary magnetic substance. that is, by a paramagnetic substance. This conclusion, however, is not generally accepted. The cause of the behavior of diamagnetic substances is by some believed to be due to the difference in the resistance which the air offers to the passage of the lines of magnetic force through it, as compared with that offered by a diamagnetic substance through it.

Diamagnetism is possessed by certain liquids and gaseous substances.

Prof. Tyndall believes that diamagnetic substances possess a polarity distinct from the ordinary magnetic polarity; he calls this diamagnetic polarity. In a work entitled "Researches in Diamagnetism and Magne-crystallic Action" * he thus refers to the matter:

On December 18th, 1845, Faraday communicated to the Royal Society a memoir on the "Magnetic Condition of All

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* "Researches in Diamagnetism and Magne-crystallic Action," by John Tyndall, D.C.L., LL.D., F. R. S. New York: D. Appleton & Co. 1888. 288 pages, 67 illustrations. Price, $1.50.

Matter." Before the pole of an electromagnet he suspended a fragment of his famous heavy glass, and observed that when the magnet was powerfully excited the glass fairly retreated from the pole. It was a clear case of magnetic repulsion. He then suspended a bar of the glass between two poles; the bar retreated when the poles were excited, and set its length equatorially or at right angles to the line joining them. When an ordinary magnetic body was similarly suspended, it always set axially, that is, from pole to pole.

He called those bodies which were repelled by the poles of a magnet diamagnetic bodies; using this term in a sense different from that in which he applied it in his memoir on the magnetization of light. The term magnetic he reserved for bodies which exhibited the ordinary attraction. He afterward employed the term magnetic to cover the whole phenomena of attraction and repulsion, and used the word paramagnetic to designate magnetic action like that of iron. * * *

Faraday's thoughts ran intuitively into experimental combinations, so that subjects whose capacity for experimental treatment would to most minds seem to be exhaustible in a moment, were shown by him to be all but inexhaustible. He had an object in view, the first step toward which was the proof that the principle of Archimedes is true of magnetism.

Faraday subsequently abandoned this belief in a distinct magnetic polarity.

EXTRACTS FROM STANDARD WORKS.

In his "Dictionary of Electrical Words, Terms and Phrases,"* page 284, under the title "*Induction, Magnetic,*" the author says:

INDUCTION, MAGNETIC.—The production of magnetism in a magnetizable substance by bringing it into a magnetic field.

Suppose a small portion of a magnetizable body is placed in a magnetic field produced in a gap separating two closely approximated poles. To simplify matters, suppose this small portion to be a free unit pole. It will be acted on by two forces:

(1.) The force due to the magnetic field.

(2.) The force due to the free magnetism which appears at the surface of the gap or cut.

The force on the unit pole is compounded of these two separate forces, and is called the *magnetic induction* of the space. Magnetic induction is, therefore, strictly speaking, a quantity.

The direction of magnetic force and the magnetic induction are the same in an air space outside a magnet. Within a bar of iron or other paramagnetic material, under induction in a magnetic field, the magnetic force at any

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* "A Dictionary of Electrical Words, Terms and Phrases," by Edwin J. Houston, A.M. New York: The W. J. Johnston Co., Ltd. 1892. 562 pages and 570 illustrations. Price, $5.00.

point is due, not only to the external or original field, also to the field produced by the polarity induced, wh acts opposed to the magnetic force at points. Magn force and magnetic induction are identical only wh there is no magnetism.—*Fleming.*

XII.—THEORIES OF MAGNETISM.

The phenomena of magnetism were known at a very early date. The curious power possessed by a magnetic needle, of pointing approximately to the earth's north pole, was known to the Chinese as early as 2,000 years B. C.

In very early times the power of the lodestone was regarded as magical. In later years considerable speculation has arisen as to the cause of this curious force. It was not until a comparatively late day, however, that anything definite has been known concerning the cause of the force of magnetism, and even yet very much remains to be discovered concerning the peculiarities of this force.

One of the earlier theories as to the cause of magnetism regarded it as due to the presence of two separate fluids, one boreal, or north, and the other austral, or south. These fluids were supposed to exist in all bodies in a state of equilibrium, or combination. In some bodies, like iron and nickel, they were capable of separation. Although the austral and the boreal fluids were capable of being separated from each other, yet it was believed that they could never be completely isolated from each other, but always existed in the same bar. In other words, no magnet could be obtained with a single pole. The fluid theory of magnetism is now abandoned.

Shortly after the discovery by Oersted of the magnetic properties of a conductor, through which a current of electricity is flowing, Ampère, the French physicist, after whom the practical unit of electric current is named, began a series of investigations as to the cause of magnetism. As a result of these investigations, Ampère proposed a theory for magnetism which, although now generally abandoned in its form as proposed by him, yet was a great advance in science, and did much to throw light on the peculiarities of this strange force.

Ampère's theory of magnetism explains the production of magnetism by the following assumptions:

(1.) That the ultimate particles of all magnetizable bodies form closed circuits, in which currents of electricity are constantly flowing.

(2.) That in an unmagnetized body these currents are still present, but that the currents flow in opposite directions in adjoining circuits, and therefore neutralize one another.

(3.) That the act of magnetization consists in such movement or polarization of the particles as will cause the currents in all to flow in one and the same direction, magnetic saturation being reached when they are all so caused to flow in one and the same direction.

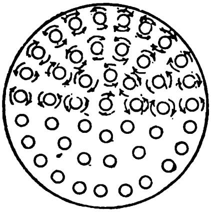

FIG. 70.—UNMAGNETIZED BAR (AFTER AMPÈRE).

(4.) That coercive force is due to the resistance which these circuits, or the particles through which they flow, offer to a change in their direction.

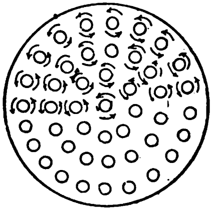

FIG. 71.—MAGNETIZED BAR (AFTER AMPÈRE).

The conditions of the circuit in a magnetized and in an unmagnetized bar according to Ampère's theory are shown in Figs. 70 and 71.

A careful inspection of these figures will show that in the case of an unmagnetized bar the separate currents are flowing in different directions, while in the case of a magnetized bar all the separate currents are flowing in one and the same general direction.

It can be shown experimentally that the magnetic effect produced in the space outside a number of separate circuits that are near together, and have currents flowing through them in opposite directions, is completely neutralized.

In the case, therefore, of a magnetized bar all the circuits, except those situated in the extreme edge of the bar, will have their currents flowing in opposite directions to those in any neighboring circuit. These currents will, therefore, neutralize one another, and the bar will act as if no such currents were present.

There will remain, however, an un-neutralized current flowing in the circuit on the outside of the bar, and this current may, therefore, be regarded as the magnetizing current.

In accordance with this theory, Ampère constructed a coil of wire, called a solenoid, which formed the equivalent of the magnetizing circuit, and which he assumed as the cause of the magnetization.

Such a solenoid consists of a coil of wire bent as shown in Fig. 72. When traversed by an electric current, it acquires all the properties of a magnet.

The solenoid shown in Fig. 73 is suspended at *P*, *P*, in two mercury cups *M*, *M*, connected to an electric source. When an electric current flows through the solenoid, the ends *A* and *B*, acquire magnetic polarity. If, therefore, the pole *B*, of an electromagnet be brought near to the end *A*, of the solenoid, the solenoid will be attracted just as an ordinary magnet would.

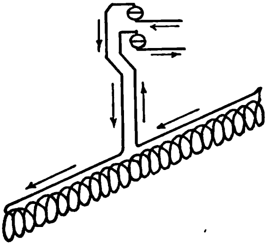

FIG. 72.—PRACTICAL SOLENOID.

The application of the solenoid to the production of an electromagnet will be more fully explained in another Primer.

The improbability of an electric current continually flowing in a circuit without any expenditure of energy has led nearly all scientific men to reject Ampère's theory of magnetism. In order to escape this difficulty, a number of different theories have been formed to account for the phenomena of magnetism.

It will be seen, however, that these theories bear a close resemblance to Ampère's theory, save only in that the ultimate particles are assumed to be originally magnetized, no explanation being given as to how they acquire such magnetization.

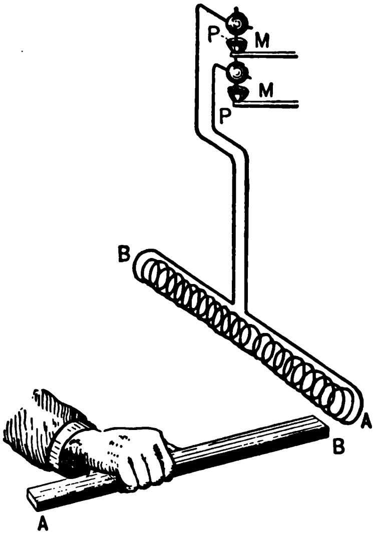

FIG. 73.—ATTRACTION OF SOLENOID BY PERMANENT MAGNET.

For example, Prof. Hughes has proposed a theory for magnetism which accounts for the phenomena of magnetism by the following assumptions:

(1.) That the ultimate particles of matter naturally possess opposite magnetic polarities; namely, +, or north, and —, or south.

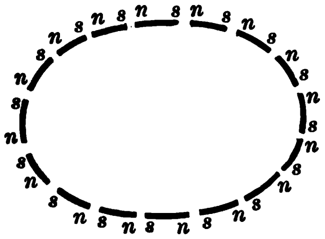

FIG. 74.—CLOSED MAGNETIC CHAIN.

(2.) That when these ultimate particles are arranged in closed chains or circuits, with their opposite poles together, they completely neutralize one another so far as any external effect is concerned.

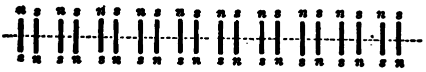

FIG. 75.—CLOSED GROUPINGS.

Two such arrangements or groupings of the ultimate particles are shown in Figs. 74 and 75.

(3.) That the act of magnetization consists in a rotation of these ultimate particles so as to cause all the positive poles to point in one and the same direction, and all the negative poles to point in the opposite direction. According to this theory, the bar will be magnetized to saturation when such polarization of all the particles is complete. It will be partly polarized when such polarization is but partial.

According to Hughes' theory, the coercive force arises from the resistance the body offers to the rotation of its particles.

The following facts would appear to strengthen Hughes' theory of magnetism :

(1.) A bar of steel or iron increases sensibly in length on being magnetized. This would follow if the particles are longer in one direction than in another. Mr. Shelford Bidwell has shown that a shortening of the substance sometimes accompanies magnetization, as in the case of nickel.

(2.) A tube furnished at its opposite ends with plates of glass, and filled with water containing any finely divided magnetizable substance in the shape of plates or scales, such, for example, as magnetic oxide of iron, is nearly opaque to light when unmagnetized. When magnetized, however, it will permit some light to pass through it, because the plates tend then to set themselves with their greatest lengths in the direction of the length of the tube.

(3.) A magnet when cut at its neutral point will possess opposite polarities at its cut ends, and, no matter to what extent such cutting or subdivision is carried, the cut particles will still possess opposite polarities.

(4.) The greater magnetic strength possessed by a bar of iron electrolytically deposited in a powerful magnetic field.

Von Betz placed a powerful horseshoe magnet in a solution of an iron salt and deposited a plate of iron by electrolysis between the poles. Under these circumstances the particles of the iron at the time of the deposition were subjected to a polarizing force which tended to place them all in the same direction, and since the state of solution in which they existed before their deposition gave them great freedom of motion, they were all presumably deposited in lines or chains parallel to one another. Therefore, when the bar was subsequently magnetized, it should, as was found to be the case, become more powerful, in proportion to its size, than any ordinary magnet.

A theory of magnetism which is in reality a modification of the above has recently been proposed by Prof. Ewing, and is now generally accepted by scientific men.

Like Hughes, Ewing assumes that the ultimate particles of matter are naturally magnetic, and possess polarity. He differs, however, from Hughes, in disbelieving in the necessity for assuming a force which resists the movement of the molecules during their polarization.

According to Ewing, no such force exists between these separate particles except such forces as would be produced by their mutual attractions and repulsions. The ultimate particles, though thus free to move, only rotate about their centres, and are maintained at constant distances from one another during such rotation.

Ewing has experimentally demonstrated the principles of his theory by means of a model in which a number of small magnetic needles are so supported as to be capable of free motion in a horizontal plane, when under varying magnetic forces.

The fact that an increase of temperature causes a total loss of magnetism in a substance is very happily explained by Prof. Ewing, on the assumption that at the high temperatures at which magnetism vanishes, the ultimate particles of the magnet ar set into actual rotation, when, of course, all influenc of their magnetic effects would disappear.

That a force suddenly applied produces a grea effect in causing magnetism than when gradu applied is thought to be due to the inertia of the particles.

It is a well-known fact that a mass of iron subjected to magnetization becomes magnetized more readily when subjected to vibrations or mechanical shocks. This fact is equally explained by the theory of Ampère, by the aid the vibrations afford in permitting the particles to rotate into positions in which their circuits are parallel, or, according to the theories of Hughes and Ewing, to rotate until they are all directed in one way, or completely polarized.

According to Ewing, magnetic hysteresis does not result from any quasi-frictional resistance to molecular rotation, but rather to the resistance which a molecule experiences in moving from any position in stable equilibrium to some other position of stable equilibrium through a position of unstable equilibrium.

"This process," says Ewing, "considered mechanically, is not reversible. The forces are different for the same displacement, going and coming, and there is dissipation of energy. In the model, the energy thus expended sets the little bars swinging, and their swings take some time to subside. In the actual solid, the energy which the molecular magnet loses as it swings through unstable positions generates eddy currents in surrounding matter. Let the magnets of the model be furnished with air vanes to damp their swings and the correspondence is complete."

Ewing discusses the theoretical effects of temperature on magnetism in the following manner: Let us suppose two moderate magnetizing forces be so applied that nothing like magnetic saturation is reached; if now the temperature be raised, then—

(1.) The magnetic permeability increases until a certain high critical temperature is reached.

(2.) At the critical temperature there is suddenly almost a complete loss of magnetic quality.

Ewing explains these facts as follows, viz.: The increase in temperature by increasing the distances between the molecular centres causes a decrease in their stability.

The loss of magnetic quality on the attaining of a certain high temperature is due to the fact that at such temperatures the magnetic molecules are set into actual rotation when all traces of polarity disappear.

EXTRACTS FROM STANDARD WORKS.

In a work entitled "Electricity in the Service of Man,"* by Wormell and Perry, page 13, the authors, speaking of magnetic induction, say:

> The behavior of magnets toward one another enables us to ascertain the magnetic condition of any piece of iron. First, present the north-seeking end of the magnet and then the south-seeking end to the piece of iron; if the piece of iron attracts both poles, it is unmagnetized, that is, it is not a magnet; but if it attracts either of the poles of the magnet, and repels the other, then it is a magnet having a north-seeking and a south-seeking magnetic pole.
>
> If we continue and vary the above experiment, we find that a piece of soft iron in the presence of a magnet is not only attracted, but becomes a magnet itself, capable of attracting another piece, which again might attract a third piece of iron, and so on; only the magnetic strength of each succeeding piece is less than that of the preceding one. On the magnet being withdrawn, all these pieces of iron become detached from each other, showing that they were only magnetized when the first piece touched the magnet.
>
> Again, if we suspend an iron bar over a surface covered with iron filings, the filings and the iron bar have no action upon each other; but if we now suspend a magnet

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* "Electricity in the Service of Man: A Popular Treatise on the Applications of Electricity in Modern Life," by R. Wormell, D. Sc., M.A., and John Perry, M.E., F.R.S. London: Cassell & Co., Ltd. 1886. 859 pages, 836 illustrations. Price, $6.00.

over the iron bar, the filings are attracted by the iron bar even when it does not touch the magnet. This effect is not lessened by placing between the bar and the magnet a sheet of glass, wood, or pasteboard. The filings, however, fall from the bar immediately on the magnet being withdrawn. If we want to ascertain the magnetic condition of the bar of iron while the magnet is above it, we can do so by means of a declination needle, and we find that the pole nearest the south-seeking pole of the magnet exhibits south magnetism, and the opposite pole north magnetism.

From this we see that the bar of iron has become a magnet for the time being, without actually being touched by the magnet. During all these experiments the original magnet may be observed to have lost nothing of its power. It is neither weakened by being used to magnetize a piece of steel, nor by acting inductively on soft iron. When pieces of iron are brought near a magnet, the magnetism of the magnet does not flow over to the piece of iron. but the latter becomes a magnet by induction. The vertical bars of iron railings often become magnetized in our latitudes, the lower ends having north seeking magnetism and the upper ends south-seeking magnetism.

Lodge, in his work entitled "Modern Views of Electricity,"* page 147, speaking of Ampère's theory of magnetism, says:

The idea that magnetism is nothing more nor less than a whirl of electricity is no new one--it is as old as Ampère.

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* "Modern Views of Electricity," by Oliver J. Lodge. London: Macmillan & Co, 1889. 422 pages, 55 illustrations. Price, $2.00.

Perceiving that a magnet could be imitated by an electric whirl, he made the hypothesis that an electric whirl existed in every magnet, and was the cause of its properties. Not, of course, that a steel magnet contains an electric current circulating round and round in it, as an electromagnet has; nothing is more certain than, that a magnet is not magnetized as a whole, but that each particle of it is magnetized, and that the actual magnet is merely an assemblage of polarized particles. The old and familiar experiment of breaking a magnet into pieces proves this. Each particle or molecule of the bar must have its circulating electric current, and then the properties of the whole are explained.

There is only one little difficulty which suggests itself in Ampère's theory—how are these molecular currents maintained? Long ago similar difficulty was felt in astronomy—what maintains the motions of the planets? Spirits, vortices, and other contrivances were invented to keep them going.

But in the light of Galileo's mechanics the difficulty vanishes. Things continue in motion of themselves until they are stopped. Postulate no resistance, and motion is essentially perpetual.

What stops an ordinary current? Resistance. Start a current in a curtain-ring, by any means, and leave it alone. It will run its energy down into heat in the space of half a second or so. But if the metal conducted infinitely well, there would be no such dissipation of energy, and the current would be permanent.

In a metal rod, electricity has to pass from atom to atom, and it meets with resistance in so doing; but who is to say that the atoms themselves do not conduct perfectly? They are known to have various infinite properties already; they are infinitely elastic, for instance. Pack up a box of gas in cotton-wool for a century, and see whether it has got any cooler. The experiment if practical should be tried; but our present experience warrants us in assuming no loss of motion among colliding atoms until the contrary has been definitely proved by experiment. To all intents and purposes *certainly* atoms are infinitely elastic; why should they not also be infinitely conducting? Why should dissipation of energy occur in respect of an electric current circulating wholly inside an atom? There is no known reason why it should. There are many analogies against it.

How did these currents originate? We may as well ask, How did any of their properties originate? How did their motion originate? These questions are unanswerable. Suffice it for us to say, there they are. The atoms of a particular substance—iron, for instance, or zinc—have an electric whirl of certain strength circulating in them as one of their specific properties.

This much is certain, that the Ampèrean currents are not produced by magnetic experiments. When a piece of steel or iron is magnetized, the act of magnetization is not an excitation of Ampèrean currents in each molecule—it is not in any sense a magnetization of each molecule. The molecules were all fully magnetized to begin with: the act of magnetization consists merely in facing them round so as to look mainly in one way—in polarizing them, in fact. This was proved by Beetz long ago: I will not stop to explain it further, but will refer students to Maxwell (vol. ii., chap. vi.)

XIII.—PHENOMENA OF THE EARTH'S MAGNETISM.

In 1836, at the suggestion of Alexander von Humboldt, a series of simultaneous observations, concerning the phenomena of the earth's magnetism, were made over portions of the earth's surface situated at considerable distances from one another.

Nearly all the European governments, and most of the scientific societies in different parts of the world, sent out expeditions to make these observations in distant countries.

By far the most valuable result obtained from these observations, which for the greater part were made in especially built observatories containing no iron in their structure, was the fact that variations in the earth's magnetism, occurring at any one part of its surface, were simultaneously attended by corresponding variations over all other parts of its surface. This practically leads to the conclusion that the earth is to be considered as one huge magnet.

We will, therefore, consider the earth to be a magnet, with its poles situated, not exactly at its north and south geographical poles, but at some little distance from them.

In reality, a careful study of the earth's magnetism has led some investigators to believe that the earth is rather like an anomalous magnet with four poles; two poles, a stronger and a weaker pole, situated in the Northern Hemisphere, and similarly two poles, a stronger and a weaker pole, situated in the Southern Hemisphere. According to Hansteen, in the Northern Hemisphere the stronger pole is situated in lat. 70° 5′ North, long. 99° 6′ West, while the weaker pole is situated in Asia, in lat. 85° 21′ North, and long. 118° 39′ East.

As in the case of an ordinary magnet, the lines of magnetic force of the earth may be regarded as coming out of the earth at its north magnetic pole, and, after spreading out through the air which covers the earth, re-entering it at its south magnetic pole.

The following facts may be noted concerning the distribution of the earth's magnetic force:

(1.) In the neighborhood of the earth's magnetic poles the number of lines of force is greater than in an equal area at any other place, and is least in the neighborhood of a line called the magnetic equator, which is situated approximately midway between the north and south magnetic poles.

(2.) The lines of magnetic force extend from one magnetic pole to the other in irregularly curved lines; or, in other words, they pass through the air outside the earth in a rather irregular manner. Their general direction, however, at any locality, coincides with the direction in which a small magnetic needle comes to rest in the earth's field. They do not, therefore, point to the true geographical north except at comparatively few places on the surface. In most places they point either to the east or to the west of the true north.

(3.) In some parts of the earth's surface the lines of magnetic force extend parallel to the surface, or are horizontal thereto, while at others they incline or dip to the surface. As a rule they are most nearly horizontal in the neighborhood of the magnetic equator and are most inclined near the earth's magnetic poles. Remembering the above principles, most of the phenomena of the earth's magnetism are readily understood.

A magnetic needle, free to move, no matter where placed on the earth's surface, will be in the earth's magnetic field, and, when displaced, will soon come to rest in a position in which the lines of the earth's magnetic force pass through or thread it in the direction of its greatest length. If a sufficiently great number of magnetic needles were placed together so as to nearly cover the earth, they would, like iron filings sprinkled over a sheet of paper held near a magnet, come to rest in the position of the earth's lines of magnetic force.

It is a mistake to suppose that a magnetic needle always points to the earth's true geographical north and south. In point of fact, there are comparatively few places on the earth's surface where the needle so points; for, since the needle comes to rest in the direction of the earth's lines of force, and since these, except at a few places on the earth's surface, do not point toward the true geographical north and south, the needle must also fail to so point.

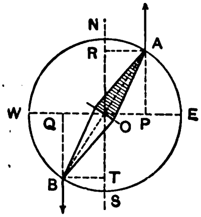


Fig. 76.—Declination of Needle.

This deviation of a magnetic needle from the true geographical north and south is called the **magnetic declination** of the needle. The magnetic declination at any place is measured by an angle called the **angle of declination**. If the line *N S*, Fig. 76, represents the true north and south line, and the magnetic needle points in the direction shown in the figure, the declination is said to be east, because the deviation is toward the east.

The declination of the magnetic needle is sometimes called the magnetic variation.

Lines connecting places on the earth's surface that have the same declination are called isogonal lines. A map or chart on which such lines are marked is called an isogonal map or chart. Such an isogonal chart is shown in Fig. 77. The position of the stronger magnetic pole in the Northern Hemisphere is shown where the isogonal lines come together at the point west of Baffin Bay. The weaker pole in Asia is marked by the position of the oval. In this map portions of the surface that possess western declination are shaded; those which possess eastern declination are left unshaded.

When a magnetic needle comes to rest in the field of another magnet, the lines of force of that magnet thread or pass through it, entering and passing out at its poles. Therefore, when a magnetic needle comes to rest in the earth's magnetic field, the lines of magnetic force will come out of that end of the needle which points approximately toward the geographical north. If, therefore, that pole of a

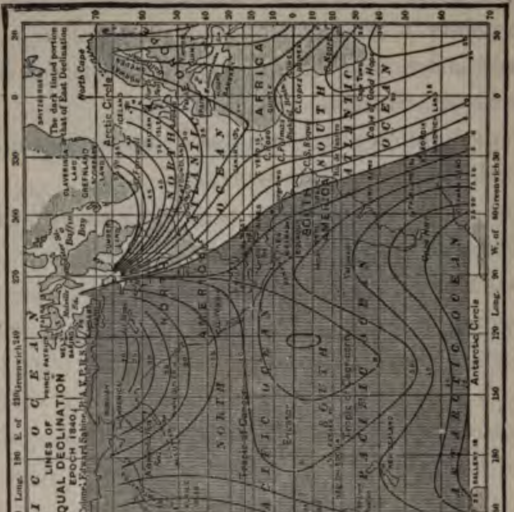


FIG. 77.—ISOGONAL MAP OR CHART.

magnetic needle out from which the lines of magnetic force come be the north pole, it is evident that such a north pole must in reality point toward the earth's magnetic south pole. The earth's magnetic pole in the Northern Hemisphere must, therefore, be a south magnetic pole.

It is for this reason that the terms north-seeking pole, or marked pole, have been applied by some to that pole of the magnetic needle which points approximately to the earth's geographical north. In this country, however, this pole is generally called the north pole, and the magnetic pole of the earth's Northern Hemisphere is regarded as the south magnetic pole. For the same reason the French formerly called that pole of the needle which points

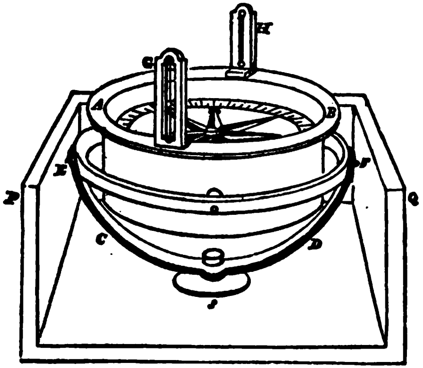


FIG. 78.—MARINER'S COMPASS.

approximately to the geographical north the austral or south pole; and the pole which points approximately to the south, the boreal or north pole.

A magnetic needle, when used as a mariner's compass, is a piece of apparatus which is absolutely essential to navigation.

A form commonly given to such a compass is shown in Fig. 78. A single magnetic needle, or several smaller magnetic needles, are placed parallel to each other on the lower surface of a card called the compass card. This card is divided into four cardinal points, N., S., E. and W., and these are again subdivided into thirty-two points called rhumbs.

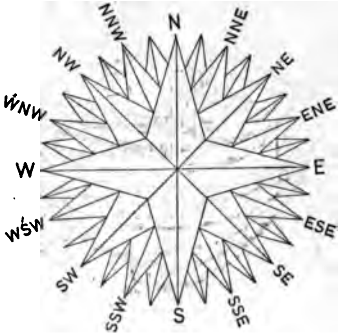


FIG. 79.—POINTS OF COMPASS.

In some cards the rhumbs are still further subdivided into degrees. Fig. 79 shows the arrangement and the names of some of the rhumbs on a compass card.

In order to insure a horizontal position of the compass, notwithstanding the rolling of the ship, it is suspended as shown in Fig. 78, on points called gimbals. These consist essentially of two axes situated at right angles to each other. In order to locate the position of a star or a distant object on the horizon, sights are provided at *G* and *H*. The magnet is placed underneath the compass card, and as the card is moved by the earth's magnetism. the amount of its motion is determined by figures marked on a graduated circle in the compass box, inside of which the card moves.

A magnetic needle comes to rest in the earth's magnetic field by reason of a magnetic couple acting on it. This will be seen from an inspection of Fig. 76, where the magnetic needle *A B*, when in any other position than in the magnetic meridian *N S*, will be acted on by two parallel equal forces acting in the direction of the arrows *A* and *B*, as shown. The effect of this couple will be to rotate the needle until it comes to rest in the magnetic meridian *N S*.

Since the magnetic needle comes to rest in the earth's field at any place, in the general direction of the earth's lines of force at that place, and since, in most places on the earth, these lines are inclined to the horizon, it follows that on most parts of the earth a magnetic needle, so supported as to be capable of motion in a vertical as well as in a horizontal plane, will not come to rest in a horizontal position, but will incline or dip with one of its poles toward earth. In the Northern Hemisphere it is the n seeking pole which will so incline, while i Southern Hemisphere it is the south-seeking

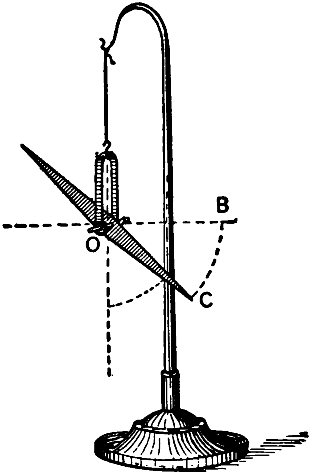


FIG. 80.—DIPPING NEEDLE.

The magnetic needle shown in Fig. 80 is sented as coming to rest in an inclined position angle *B O C*, which marks the deviation of the needle from the horizontal line *O B*, is called the angle of dip, or the magnetic inclination of the needle.

In order to measure the magnetic inclination or dip at any place an instrument called an inclination or dipping compass is employed.

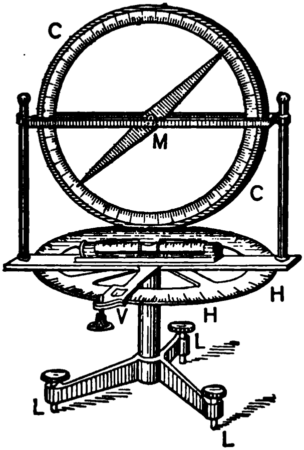
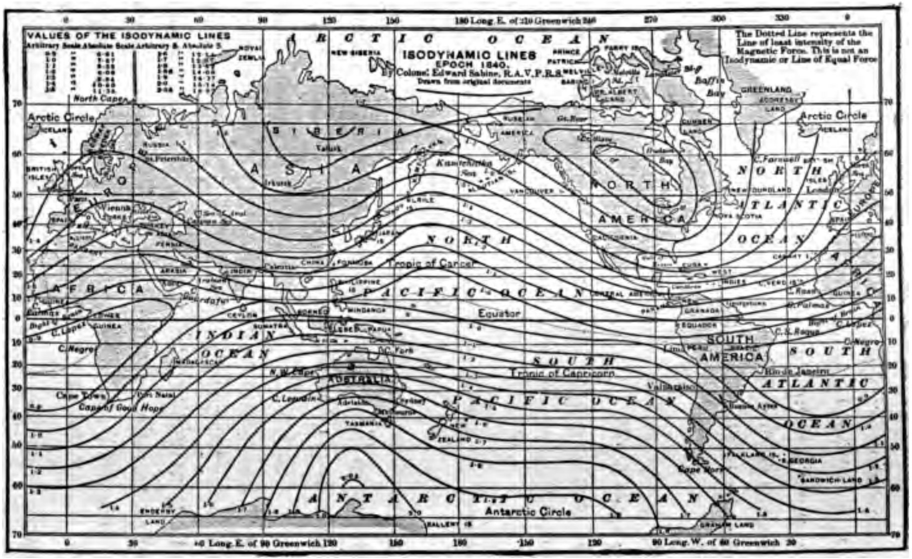


FIG. 81.—INCLINATION OR DIPPING COMPASS.

A well-known form of dipping or inclination compass is shown in Fig. 81. It consists essentially of a magnetic needle *M*, supported so as to be free to move in a vertical plane only. In order to measure the angle of dip the vertical circle *C C*, is first moved over the horizontal circle *H H*, until the needle dips vertically downward. The vertical plane in which the needle is free to move is now situated at right angles to the plane of the magnetic meridian, or in the line extending directly through the axis of the needle when it comes to rest in the earth's field. The vertical circle is now moved through an angle of 90° from this position, when the true angle of dip is measured on the vertical circle *C C*. These steps are necessary, because, when free to move in one plane only, the needle will not indicate the true angle of dip in any other position than in the plane of the magnetic meridian.

We have already seen that the number of the lines of magnetic force that pass through a given unit of area of cross section is different at different parts of the earth's surface. Since the intensity of magnetism depends on the number of lines of force that pass through a given space, it follows that the intensity of the earth's magnetism will be greater in some places than in others. This intensity is greatest in the immediate neighborhood of the earth's magnetic poles, and is weakest at the earth's magnetic equator.

The intensity of the earth's magnetism at any place is determined by counting the number of oscillations which a small magnetic needle makes in a


VALUES OF THE ISODYNAMIC LINES
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EPOCH 1840.
By Colonel Edward Sabine, R.A.V.P.R.S.
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The Dotted Line represents the Line of least intensity of the Magnetic Force. This is not an Isodynamic or Line of Equal Force
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SIBERIA
ASIA
EUROPE
AFRICA
INDIAN OCEAN
AUSTRALIA
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
Tropic of Cancer
Equator
Tropic of Capricorn
NORTH AMERICA
SOUTH AMERICA
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
ANTARCTIC OCEAN
Antarctic Circle
GREENLAND
Baffin Bay
Cape of Good Hope
Cape Horn
180 Long. E. of 210 Greenwich 240
90 Long. W. of 60 Greenwich 30
+0 Long. E. of 90 Greenwich 120

FIG. 89.—ISODYNAMIC MAP OR CHART.

given time, when slightly disturbed from its position of equilibrium in the earth's field, before it comes to rest.

Suppose, for example, that such a needle at one place makes 211 oscillations in ten minutes, while at another place it makes 254 oscillations in the same time; then the relative magnetic intensities of these places are as the squares of these numbers; i. e., as 44521 : 60025; or, as 1:1.348.

Lines connecting places on the earth that have the same magnetic intensity are called isodynamic lines, and a map or chart, on which such lines are marked, is called an isodynamic map or chart.

Such an isodynamic map or chart is shown in Fig. 82.

Lines connecting places on the earth's surface which possess the same angle of dip are called isoclinal lines. A map or chart, on which such lines are marked, is called an isoclinal map or chart. Such a map or chart is shown in Fig. 83.

The magnetism of the earth is constantly undergoing changes or variations. If its lines of force were visible to the outward eye, they would be seen at times throbbing, slightly changing their direction and position, and becoming more densely crowded together in certain regions and more separated in others.

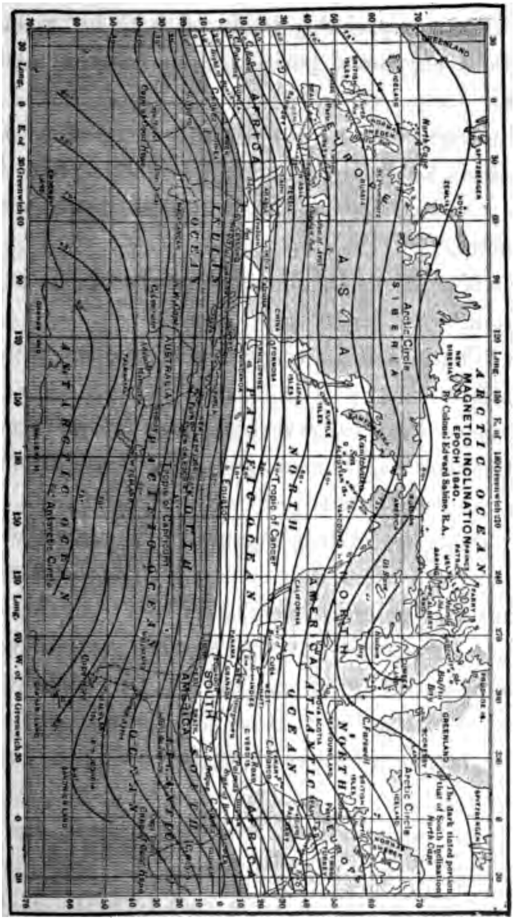

FIG. 83.—ISOCLINAL MAP OR CHART.

These variations in the grouping and position of the lines are probably produced both by variations in the strength and position of the earth's magnetic poles.

The variations in the earth's magnetism may, therefore, be arranged under three heads; namely,

(1.) Variations in the value of the magnetic intensity.

(2.) Variations in the value of the magnetic declination.

(3.) Variations in the value of the magnetic inclination.

Various theories have been proposed to account for the causes of the earth's magnetism. The most important of these theories are as follows; viz.,

I. That the earth's magnetism is caused by electric currents which flow or pass around the earth.

Various agencies have been ascribed as the cause of such currents; such, for example, as differences of temperature produced in different parts of the earth's crust as it rotates on its axis, and thus brings various portions of its surface directly under the sun's rays.

As the earth rotates from west to east, the area of greatest heat will move around the earth in the opposite direction, or from east to west. If, now, such differences of temperature could produce thermo-electric currents circulating around the earth from east to west, these currents would cause a magnetic pole of south polarity to be produced in the Northern Hemisphere and a magnetic pole of north polarity in the Southern Hemisphere, and thus account for the polarity possessed by the earth.

An objection to this theory is to be found in the fact that the greater part of the earth's surface at the equator is composed of water, so that it is difficult to see exactly how differences of temperature could be so set up in the earth's crust as to cause the difference of potential required.

II. That the earth's magnetism is caused by induction from an already magnetized sun. This theory was proposed by Secchi and others, but is not generally credited.

III. That the earth's magnetism is caused by its rotation in the magnetic field of the sun's radiant energy; that is, in the sunshine. This theory was proposed by Biglow.

It will be noticed that in all these theories the sun is assumed as the prime factor in the production of the earth's magnetism.

That there is necessarily some connection between the sun and the earth's magnetism is unquestionably approximately to the geographical north the austral or south pole; and the pole which points approximately to the south, the boreal or north pole.

A magnetic needle, when used as a mariner's compass, is a piece of apparatus which is absolutely essential to navigation.

A form commonly given to such a compass is shown in Fig. 78. A single magnetic needle, or several smaller magnetic needles, are placed parallel to each other on the lower surface of a card called the compass card. This card is divided into four cardinal points, N., S., E. and W., and these are again subdivided into thirty-two points called rhumbs.

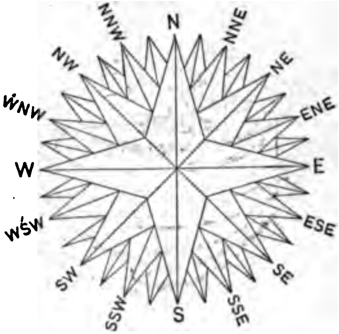

FIG. 79.—POINTS OF COMPASS.

In some cards the rhumbs are still further subdivided into degrees. Fig. 79 shows the arrangement and the names of some of the rhumbs on a compass card.

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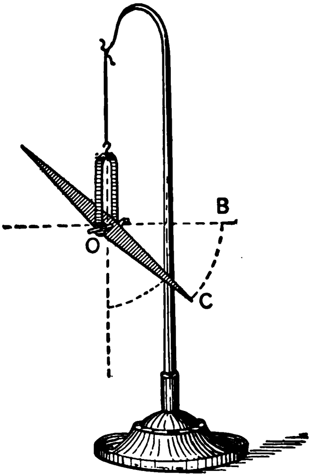

FIG. 80.—DIPPING NEEDLE.

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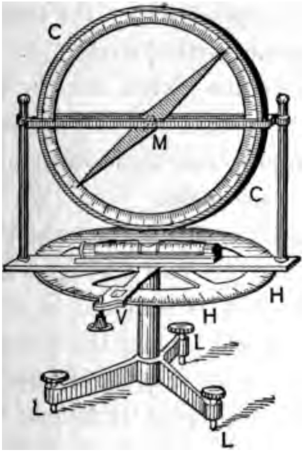

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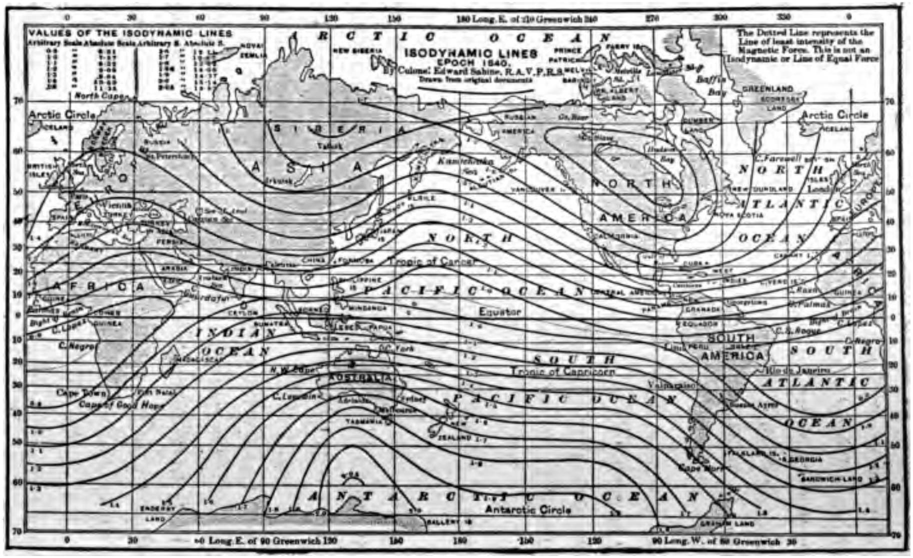
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SOUTH PACIFIC OCEAN
NORTH AMERICA
SOUTH AMERICA
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
EUROPE
GREENLAND
ANTARCTIC OCEAN
Antarctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Cape Town
Cape of Good Hope
Cape Horn
Kamtschatka
Baffin Bay
Vienna
Valparaiso
Rio de Janeiro

FIG. 82.—ISODYNAMIC MAP OR CHART.

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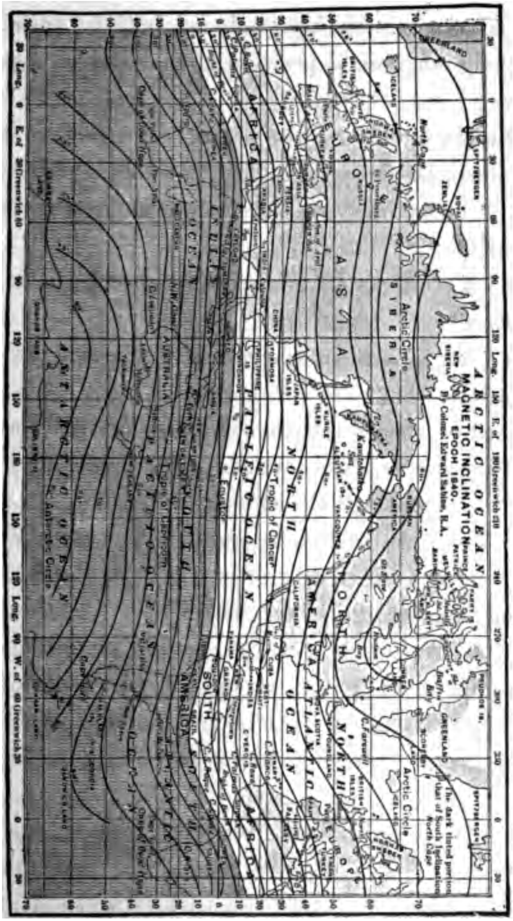

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It will be noticed that in all these theories the sun is assumed as the prime factor in the production of the earth's magnetism.

That there is necessarily some connection between the sun and the earth's magnetism is unquestionably established from the well-known coincidence existing between the times of unusual disturbance in the earth's magnetism, known as magnetic storms, and those outbursts of solar energy known as sun-spots.

The results of a series of observations on the number and frequency of such spots are plotted in the form of the curve shown in Fig. 84.

Here the distances taken in one direction along lines represent the times of occurrence of the sun-spots, and those taken in a direction at right angles to such lines represent the number of sun-spots. Such a curve agrees in a remarkable manner with a curve similarly constructed by reference to the times of occurrence and the frequency of magnetic disturbances. In the chart the full lines represent the curves of sun-spots; the dotted lines, the curves of magnetic storms.

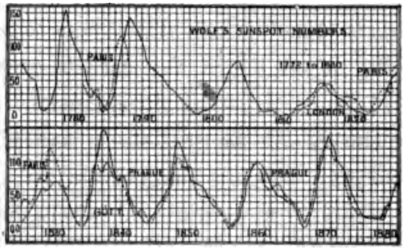

FIG. 84.—WOLF'S SUN-SPOT NUMBERS.

EXTRACTS FROM STANDARD WORKS.

In their "Practical Notes for Electrical Students,"* Vol. I., page 133, Kennelly and Wilkinson thus describe some of the phenomena of the earth's magnetic field :

> If a light strip of steel be mounted at its centre on a horizontal axis so that it is perfectly balanced and free to move in a vertical plane, and it is then taken off the pivot and subjected to the process of magnetization, it will be found on replacing it in its bearings that it will appear to have one end heavier than the other ; that is, the rod will take up a definite inclined position, and will not remain in any other position but this. This effect is due to the magnetic field of the earth, and in our latitude it is the north pole of the pivoted magnet which is so "inclined" or "dipped" downward. By the exploration of the magnetic field of an ordinary bar magnet (as shown in Fig. 60) it may be noticed that the suspended needle "dips" when near either pole ; but when over the centre or equator of the magnet it remains horizontal, and we account for the effects observed on the surface of our globe by imagining its axis to be a huge magnet, whose north pole lies toward the geographical south, and whose south pole lies toward the north. If we shift the position of the magnetized steel

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* "Practical Notes for Electrical Students," Vol. I., by A. E. Kennelly and H. D. Wilkinson. London: The Electrician Publishing Company. 1890. 308 pages, 155 illustrations. Price, $2.50.

strip until it is free to move in a vertical plane *coinciding* with the direction of the magnetic meridian, we have the greatest angle of dip ; that is, the magnetized strip takes up the direction in which the "intensity" of the earth's field is greatest.

The angle which the strip or needle so inclined makes with the horizontal is termed the angle of "*Dip*" or "*Inclination*." As we go further north, the "angle of dip" increases, and we should expect to find the needle nearly vertical in regions near the geographical north pole· Similarly, on going south the "dip" decreases until there is no dip at all. We are then on the "magnetic equator" of our globe, and this equator, in which there is no angle of dip, runs very nearly through Aden, Madras, Penang and Borneo, being several degrees north of the geographical equator. Going further south still, the needle "dips" the other way, that is, with its south pole downward, the angle of dip at the city of Melbourne being about the same as in London now, viz., about 67 degrees. At the time it was first observed in the year 1576, it was 71° 50′ in London, and it steadily increased, until 147 years after that time it had reached 74° 42′, since which, down to our present time, it has been slowly decreasing.

It is not within the scope of these papers to describe the methods of taking measurements of terrestrial magnetism ; these are continually carried out at the different observatories, with instruments of great precision, as for example at Kew and Greenwich, and continuous records are kept.

The "*Total Intensity*" of the earth's field is the intensity measured in a direction inclined to the horizontal by the angle of dip or inclination, and in the vertical plane of the magnetic meridian. In order to express this total intensity in units of magnetic measurement, or indeed to express the strength of any magnetic field in units we must first define the unit magnetic pole and the unit of force.

Silvanus P. Thompson in his excellent little book entitled "Electricity and Magnetism,"* on page 113, thus refers to the magnetism of the earth :

Gilbert made the great discovery that the compass needle points north and south because the earth is itself also a great magnet. The magnetic poles of the earth are, however, not exactly at the geographical north and south poles. The magnetic north pole of the earth is more than 1,000 miles away from the actual pole, being in lat. 70° 5′ N. and long. 96° 46′ W. In 1831 it was found by Sir J. C. Ross to be situated in Boothia Felix, just within the Arctic Circle. The south magnetic pole of the earth has never been reached ; and by reason of irregularities in the distribution of the magnetism there appears to be two south magnetic polar regions.

In consequence of this natural distribution the compass-needle does not at all points of the earth's surface point truly north and south. Thus, in 1881, the compass-needle at London points at an angle of about 18° 33′ west of the true north. This angle between the "magnetic meridian" and the geographical meridian of a place is called the magnetic declination of that place. The existence of this declination was discovered by Columbus in 1492, though it appears to have been known previously to the Chinese, and it is said to have been noticed in Europe in the early part of the 13th century by Peter Pellegrinus. The discovery is also claimed, though on doubtful authority, for Sebastian Cabot. The fact that the declination differs at different points of the earth's surface is the undisputed discovery of Columbus.

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* "Elementary Lessons in Electricity and Magnetism," by Silvanus P. Thompson. London: Macmillan & Co. 1884. 456 pages, 171 illustrations. Price, $1.25.

In order that ships may steer by the compass, magnetic charts must be prepared and the declination at different places accurately measured. The upright pieces *P P′*, on the "azimuth compass" drawn in Fig. 78, are for the purpose of sighting a star whose position may be known from astronomical tables, and thus affording a comparison between the magnetic meridian of the place and the geographical meridian and of measuring the angle between them.

XIV.—ELECTROMAGNETS.

In 1819, Oersted, of Copenhagen, made the important discovery that a conductor through which a current of electricity is passing acquires thereby all the properties of a magnet. That an intimate relation existed between electricity and magnetism had been suspected long before this date, but this was not definitely established until Oersted, by simply closing the circuit of a voltaic battery, found that under these circumstances the circuit possessed the power of attracting a magnetic needle brought near it; or, in other words, acquired the properties of a magnet.

This exceedingly important elementary fact in electro-magnetism can be shown in a variety of ways.

If, for example, a wire or other conductor, through which a current of electricity is passing, be held near a freely movable magnetic needle, the needle will move and will tend to set itself at right angles to the conductor.

The same thing can also be shown by means of a small floating coil of wire through which an electric current is passing, as in Fig. 85. Here a coil of insulated wire is supported by a small voltaic cell that is floated on the surface of an acid liquid in any suitable vessel. The liquid acts as the exciting liquid of the floating voltaic cell. If the current pass through the wire coil in the direction indicated by the arrows, the north pole of a magnet when brought near the coil will attract it.

In this case, as in all similar cases of magnetic attraction, the attraction is mutual; that is, the magnet attracts the coil and the coil attracts the magnet.

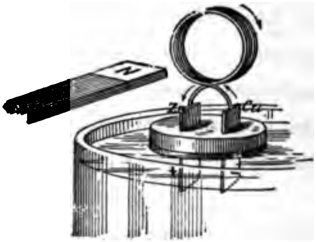

FIG. 85.—FLOATING ELECTROMAGNETIC COIL.

Since an electric current passing through a conductor renders the conductor a magnet, the conductor must possess a magnetic field.

That a conductor possesses a magnetic field while a current of electricity is passing through it can be shown by passing a straight conductor vertically through a hole at the centre of a stiff card, or a glass plate, and sprinkling iron filings on the card or plate.

If, now, while a strong discharge is passing through the conductor, the plate or paper be gently tapped, the iron filings will arrange themselves in the form of concentric circles or rings around the conductor, as shown in Fig. 86.

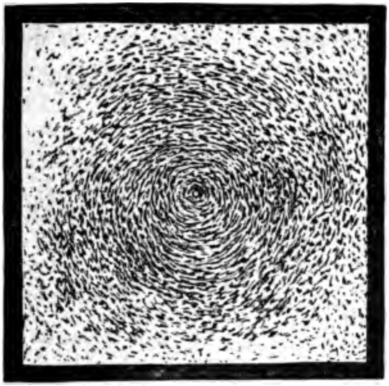

FIG. 86.—FIELD OF CURRENT.

When a magnetizable substance is brought into the field of an electric current, so that the lines of magnetic force pass through it, the substance will become magnetic and the polarity produced will depend on the direction in which the lines of magnetic force pass through it.

When the direction in which an electric current flows through a conductor is reversed, the magnetic polarity it produces is also reversed. The direction of the lines of force produced by an electric current, therefore, depends on the direction in which the current flows.

It will, therefore, be necessary to determine the direction which the lines of magnetic force must be assumed to take in such a field, in order to conform to the convention already made that the lines of magnetic force come out of a magnet at its north pole, and re-enter or pass into it at its south pole.

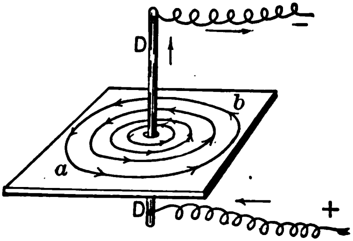

FIG. 87.—DIRECTION OF LINES OF FORCE OF CURRENT.

If an electric current be sent through a conductor *D*, Fig. 87, so as to flow directly toward an observer, placed so as to look directly down on a plane at right angles to the conductor, then, the magnetic polarity produced will be such that the circular lines of magnetic force surrounding the conductor must be assumed to take a direction *opposite* to that which the hands of an ordinary clock take, or in the direction shown by the curved arrows in the figure.

If, however, the observer be placed so as to observe these same lines from below, that is, if the current is flowing away from him, the lines will, of course, appear to take a direction the *same* as that of the hands of a clock.

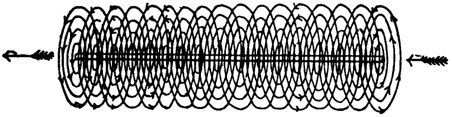

FIG. 88.—DIRECTION OF LINES OF FORCE OF CURRENT.

The direction in which the lines of force circulate around the entire length of the conductor, when the current is flowing from the right to the left, is shown in Fig. 88.

As the strength of an electric current increases, the lines of magnetic force produced increase in number and spread outward from the conductor. As the current decreases in strength, such lines decrease in number and move inward toward the conductor. When, therefore, the current flowing through a conductor rapidly undergoes variations in its strength, there is thereby produced a wave motion in the ether surrounding the conductor. Hertz has called such waves electromagnetic waves or radiations.

We have already seen how Ampère utilized the magnetic field, produced by a conductor through which an electric current is passing, to produce a magnetic solenoid.

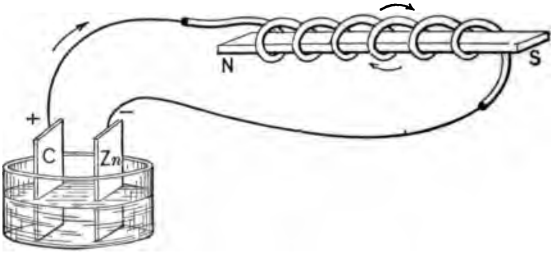

FIG. 89.—AN ELECTROMAGNET.

An application of a solenoid for the production of magnetism by the field produced by a current of electricity is shown in Fig. 89, where the current of a voltaic cell is represented as passing through a conductor, coiled around a bar of soft iron, *N S*. This current, flowing in the direction of the arrows, produces the magnetic poles *N* and *S*, in the positions marked. A magnet produced in this way by an electric current is called an electromagnet.

As now generally employed, the term electromagnet is limited to the case of a magnet produced by an electric current flowing through a coil, the core of which is made of soft iron, and which therefore instantly loses its magnetism on the cessation of the magnetizing current. In all such cases, however, unless the iron is very soft, and other precautions are taken, a small quantity of magnetism, called the residual magnetism, is retained by the magnet on the opening of the circuit.

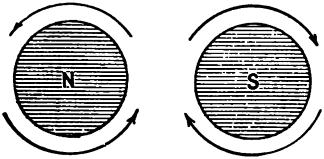

FIG. 90.—NORTH AND SOUTH MAGNET POLES.

The character of the polarity produced in an electromagnet depends:

(1.) On the direction in which the coil is wound.

(2.) On the direction in which the current passes through the coil; *i. e.*, as to which end of the coil the positive terminal of the battery or other source is connected.

No matter what may be the direction of the winding, however, the polarity of the coil is reversed, if the connections of its terminals to the source are reversed.

The direction necessary for a current to pass through a coil in order to produce a north pole at the end facing an observer is shown to the left, and that required to produce a south pole to the right of Fig. 90.

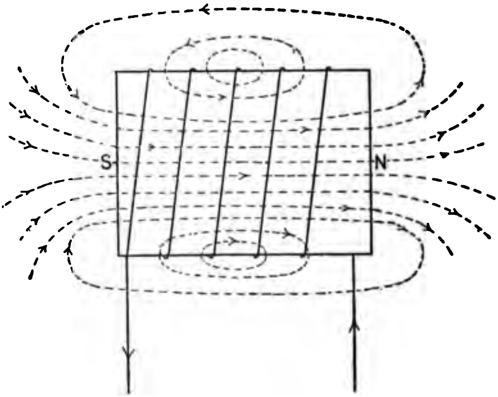

FIG. 91.—DIRECTION OF LINES OF FORCE.

The cause of the difference of polarity produced by the field of an electric current will be understood from a study of the direction taken by the lines of magnetic force produced by the current.

Suppose, for example, that an insulating, conducting wire be wrapped around a bar of soft iron as shown in Fig. 91. Bearing in mind that the direction of the lines of force is the same as that of the hands of a watch, when the current is flowing away from the observer, then the direction which these lines will take will be that shown in figure. When a bar or core of soft iron is placed inside this coil, the lines of force will enter and pass through it in the direction shown. That end of the bar, therefore, out from which these lines pass will be the north pole of the magnet, and that end into which they pass will be the south pole.

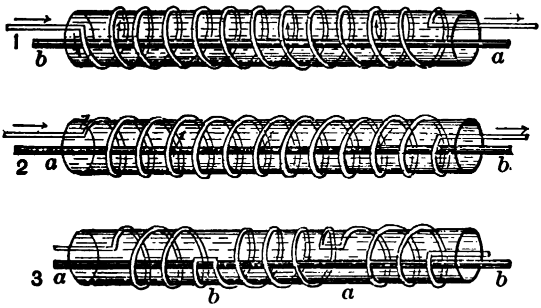

FIG. 92 —RIGHT-HANDED, LEFT-HANDED AND ANOMALOUS HELICES.

In Fig. 92, a number of coils of wire or helices are shown, in which the coils are wrapped in different directions. Three such coils are here shown.

(1.) A right-handed helix at 1.

(2.) A left-handed helix at 2.

(3.) A helix wound for the production of anomalous poles at 3.

In Fig 93 is shown a form very often given to the electromagnet. This, as will be seen, consists of two coils of insulated wire wrapped around two cores of soft iron that are joined together by a yoke or piece of soft iron at one end, and whose free ends form the poles of the magnet. The coils of wire are so wound that when connected at one set of ends, and an electric current is passed through the coils by connecting an electric source to their other ends, a north and a south pole is produced at the free ends of the core.

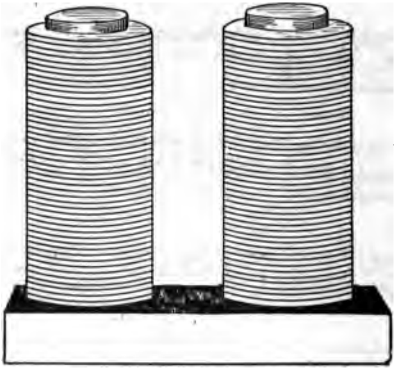

FIG. 93.—ELECTROMAGNET.

In order to understand how the passage of an electric current through the magnetizing coils, that are placed on the core of an electromagnet, produces poles therein, attention is again called to Fig. 92. If a current be sent through the right-handed helix at 1, from *b* to *a*, that is, from left to right, it will produce a south pole at *b*, and a north pole at *a*. If, however, it be sent through this helix from *a* to *b*, or from right to left, the polarity will be reversed.

If the current be sent through the left-handed helix shown at 2, from *a* to *b*, or from left to right, a north pole will be produced at *a*, and a south pole at *b*; if, however, the direction be reversed, the polarity will also be reversed.

In order to understand the method of winding an electromagnet, let us suppose that a coil of insulated wire is wrapped around a long, straight core. The coil is wrapped continuously around the core from one end to the other. Let us say from left to right.

When one layer has thus been placed over the core, a second layer is placed on top of this and the winding now proceeds from right to left. On reaching the end of the core to the left, a third layer is now wound on the second from left to right, and so on, until a sufficient number of layers have been wound on the core. If, now, this straight core be bent into the form of a horseshoe magnet, the coils will be wound on the two separate legs in the manner required to produce north and south poles respectively at the ends of the bar.

When an electric current is sent through such a magnetizing coil, as it enters the coil it will pass through the first layer of the wire, let us say from left to right, as before the coil was bent. On passing through the second layer it will flow, however, from right to left; it will pass through the third layer from left to right; through the fourth layer from right to left, and so on until it emerges at the other end of the magnetizing coil.

Now the changes in the direction of the current, which occur at the ends or poles of an electromagnet, where the current passes from one layer to the next succeeding layer, cause it to produce poles of the same name at each of such ends. Consequently, the strength of the magnetization produced will, in general, increase with the number of layers of wire through which the current is caused to pass.

The following laws express the more important principles concerning electromagnets:

(1.) The strength of an electromagnet is nearly proportional to the strength of the magnetizing current, provided the core is not saturated.

(2.) The strength of an electromagnet is proportional to the number of turns of wire on the magnetizing coil; or to the number of ampère turns: i. e., the turns through which one ampère of current flows.

A short interval of time is required for a current to thoroughly magnetize a powerful electromagnet. A short interval of time is also required for such a magnet to thoroughly lose its magnetism. Nevertheless, an electromagnet is capable of losing and acquiring its magnetism with great rapidity. It is, indeed, this property of the electromagnet that renders it of such great value in so many of the practical applications of electricity.

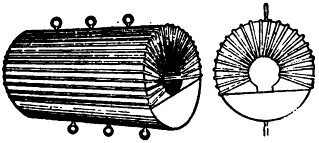

FIG. 94.—CYLINDRICAL ELECTROMAGNET.

Various shapes are given to electromagnets. The horseshoe form already shown in Fig. 93 is the commonest of these forms. There are a variety of horseshoe electromagnets.

The variety of horseshoe magnet shown in Fig. 94 is called the cylindrical electromagnet. It was devised by Joule. The core of this form of magnet consists of a hollow cylinder provided with a slot extending parallel to the axis. The gap in the cylinder suffices for the placing of the magnetizing coils, and also forms its poles as shown.

One of the advantages possessed by a horseshoe magnet arises from the fact that its opposite poles are brought near together and, therefore, their attraction for an armature of soft iron is greatly increased.

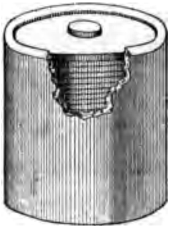

FIG. 95.—IRON-CLAD ELECTROMAGNET.

Another advantage arises from the fact that the air space or gap, through which the lines of magnetic force pass from one pole to the other, is considerably decreased, and, therefore, the resistance of the magnetic circuit becomes smaller.

The form of magnet shown in Fig. 95 is called the iron-clad magnet. It consists of a magnet with a straight core, but has its magnetizing coils almost entirely surrounded by iron. The effect of this is to greatly decrease the resistance of the magnetic circuit, and also to bring the opposite poles near to one another, and thus to greatly increase the force with which they act on an armature.

When it is desired to obtain a number of poles on the same bar, the magnetizing coils may be wound in the manner shown in Fig. 96. In this case the magnet is called a zigzag electromagnet. Its polarity will be alternately north and south as shown.

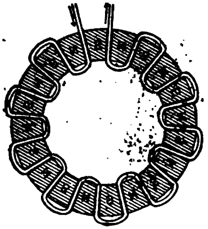

FIG. 96.—ZIGZAG ELECTROMAGNET.

A very important form of electromagnet is called a solenoidal magnet. In Fig. 97 is shown the winding of the coil for this form of magnet. The magnetizing coils are wound around a cylinder, which is afterward removed, for the insertion of the movable core. In a solenoidal magnet the core is moved or sucked into the magnetizing coils by their attraction, or is expelled therefrom by their repulsion. In such a magnet the motion of the core in one direction is obtained by the force of magnetism and the motion in the opposite direction by the action of a weight or spring.

Such a magnet is especially employed where it is desired to obtain a wide range of motion of the armature or movable core for a great variety of purposes.

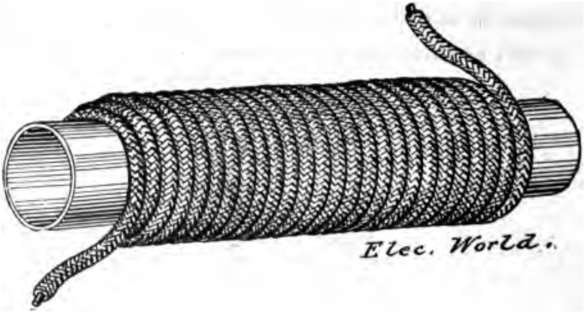

FIG. 97.—COIL FOR SOLENOIDAL MAGNET.

When a core of uniform diameter is drawn into a cylindrical coil, the attraction or pull is not uniform in strength for different positions of the bar. As the bar or core is just entering the solenoid, the magnetic pull is strongest. As soon as the core passes the middle of the coil, the attraction decreases, and, when the centres of the core and the coil coincide, the motion ceases, because, in this position, both ends of the solenoid attract equally in opposite directions.

By proportioning the core as shown in Fig. 98, so as to obtain a greater mass of material near the middle portion, a fairly uniform pull may be obtained throughout a considerable length of the core. Such shaped cores are known technically as Krizik's bars or cores.

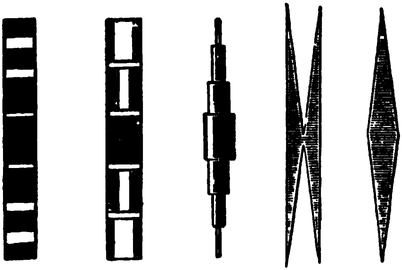

FIG. 98.—KRIZIK'S BARS OR CORES.

The following effects are produced by placing a core of soft iron within a magnetizing coil; namely,

(1.) The lines of force produced by the coil are concentrated on, and pass through, the path provided by the core.

(2.) The closed magnetic circuits, which are believed to exist naturally in the ultimate particles of the iron, open out ,or unclose, when the iron is placed in a magnetic field, and are added to the lines of force produced by the current itself. This opening out of the closed lines of magnetic force of the ultimate particles is, therefore, attended by the formation of new lines of polarized particles.

According to Lodge, there are, roughly speaking, for every single line of force produced by an electric current, some three thousand lines of magnetic force added to it from the iron. The number, however, will vary with the physical condition of the iron and with the degree of its magnetization.

EXTRACTS FROM STANDARD WORKS.

S. P. Thompson, in his "Lectures on the Electromagnet,"* page 110, in referring to the action which the magnet exerts in attracting a piece of iron at a distance, says:

What is the law of force of a magnet—or electromagnet—acting at a point some distance away from it? I have a very great controversy to wage against the common way of regarding this. The usual thing that it is proper to say is that it all depends on the law of inverse squares. Now, the law of inverse squares is one of those detestable things needing to be abolished, which. although it may be true in abstract mathematics, is absolutely inapplicable with respect to electromagnets. The only use, in fact, of the law of inverse squares, with respect to electromagnetism, is to enable you to write an answer when you want to pass an academical examination, set by some fossil examiner, who learned it years ago at the university, and never tried an experiment in his life to see if it was applicable to an electromagnet. In academical examinations they always expect you to give the law of inverse squares. What is the law of inverse squares? We had better understand what it is before we condemn it. It is a statement to the following effect—that the action of the magnet (or of the pole, some people say), at a point at a distance away from it, varies inversely as the square of the distance from the pole. There is a certain action at one inch away. Double the distance; the square of that will be four, and, inversely, the action will be one-quarter; at double the distance the action will be one-quarter; at three times the distance the action is one-ninth, and so on. You just try it with any electromagnet; nay, take any magnet you like, and unless you hit upon the particular case, I believe you will find it to be universally untrue. Experiment does not prove it.

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* "Lectures on the Electromagnet," by Silvanus P. Thompson. 1891. New York: The W. J. Johnston Co. Ltd. 288 pages, 75 illustrations. Price $1.00.

Coulomb, who was supposed to establish the law of inverse squares by means of the torsion balance, was working with long thin needles of specially hard steel, carefully magnetized, so that the only leakage of magnetism from the magnet might be as nearly as possible leakage in radiating tufts at the very ends. He practically has point poles, when the only surface magnetism is at the end faces, and the magnetic lines leak out like rays from a centre, in radial lines. Now the law of inverse squares is never true, except for the action of points; it is a *point* law. If you could get an electromagnet or a magnet with poles so small in proportion to its length that you can consider the end face of it as the only place through which magnetic lines leak up into the air, and the ends themselves to be so small as to be relatively mere points; if, also, you can regard these end faces as something so far away from whatever they are going to act upon that the distance between them shall be large compared with their size, and the end itself so small as to be a point, then, and then only, is the law of inverse squares true. It is a law of the action of points.

XV.—ELECTROSTATIC INDUCTION.

An electrically charged body, like a magnet, possesses a field of influence which surrounds it. This field is called the electrostatic field, and is traversed by lines of electrostatic force. When a conductor is brought into this field, it becomes electrified by what is called electrostatic induction.

Electrostatic attractions and repulsions take place along, or in the direction of, lines of electrostatic force. Electric level or pressure is measured along such lines of force.

If, as in Fig. 99, an insulated conductor *A B*, is brought into the electrostatic field produced by the positively charged body *C*, then :

(1.) A charge will be produced on *A B*, as will be shown by the repulsion of the pith balls attached thereto.

(2.) This charge will be negative at the end *A*. nearest *C*, and positive at the end *B*, furthest from *C*.

(3.) The charges at *A* and *B*, are equal in amount; for, if, without touching the insulated conductor *A*

B, it be removed from the field of *C*, the opposite charges at *A* and *B*, will completely neutralize each other.

(4.) If, however, the conductor *A B*, be touched at any point by an earth-connected conductor, it will lose its positive charge and will then remain negatively charged although removed from the field of *C*.

(5.) The amount of the opposite charges produced by electrostatic induction can never be greater than the charge in the inducing body *C*, that is to say, the induced negative charge at *A*, may be sufficient in amount to neutralize the positive charge *C*, if allowed to do so, but can never be greater than this amount. In point of fact, this charge is generally less than the induced charge.

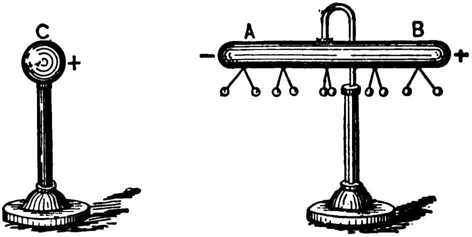

FIG. 99.—ELECTROSTATIC INDUCTION.

It will now be understood that the cause of the attraction of bodies by electric charges is a case of electrostatic induction. In all such cases induction precedes attraction and the attraction is due to the opposite charge produced at those parts of the attracted body that lie nearest the attracting body.

For example, a pith ball *B*, suspended as shown in Fig. 100, between the insulated charged conductor *A*, and the earth-connected conductor *C*, will receive by induction a negative charge on the side which lies nearest to *A*, and a positive charge on the side which lies furthest from *A*. It will, therefore, be attracted to *A*, where, receiving a positive charge, it will be repelled to *C*, where it is discharged and tends to assume a vertical position. Induction, however, again takes place, and successive attractions and repulsions follow one another as long as a sufficient charge remains on *A*.

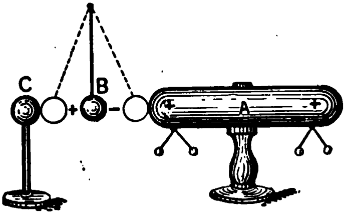

FIG. 100.—INDUCTION PRECEDES ATTRACTION.

Electrostatic attractions and repulsions of this character occur in the well known piece of apparatus called the electric chimes, shown in Fig 101, Here two bells, *B*, *B*, are electrically connected to the positive or prime conductor of an electrical machine. The central bell *C*, is insulated from these conductors by means of the silk thread by which it is hung, but it is connected to the ground by means of the metal chain as shown. Under these circumstances metallic clappers *l*, *l*, insulated by silk threads *t*, *t*, are attracted to the bells by means of the induced charges produced in them under the influence of electrostatic induction from *B*, *B*, and, receiving positive charges, are then repelled to *C*, where, losing their charges, they are again attracted to *B*, *B*. In this manner the bells will continue to ring as long as the electric machine is kept in motion.

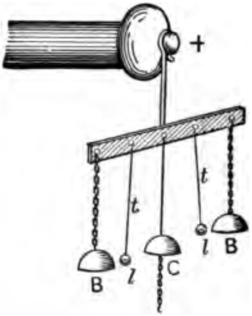

FIG. 101.—ELECTRIC CHIMES.

The amount of the electric charge produced by electrostatic induction depends :

(1.) On the amount of charge on the inducing body; or, in other words, on the strength of the electrostatic field.

(2.) On the distance the body receiving the charge is from the inducing body.

(3.) On the character of the medium which separates the inducing from the induced body.

Substances which permit electrostatic induction to take place through them are called dielectrics.

Dielectric substances differ greatly in the ease with which they permit electrostatic induction to take place through them; that is, they differ in what is called their dielectric capacity, or in their specific inductive capacity.

In order to measure the specific inductive capacity of different substances, Faraday employed the apparatus shown in Fig. 102, in which an insulated metallic sphere *A*, is placed inside a hollow metallic sphere *B*, and the cylindrical space between *A* and *B*, filled with the material whose specific inductive capacity is to be measured.

The specific inductive capacities of most substances are compared with that of air. As a rule, good dielectrics are also good insulators or poor conductors. In the following table the specific inductive capacities of a few well known dielectrics is given :

Air	1.00	Petroleum	2.030 to 2.070
Glass	3.013 to 3.258	Paraffine (solid)	1.994
Shellac	2.740	Carbon bisulphide	1.810
Sulphur	2.580	Carbonic acid	1.00036
Gutta percha	2.462	Hydrogen	0.99967
Ebonite	2 284	Vacuum	0.99941
India-rubber	2.220 to 2.497		

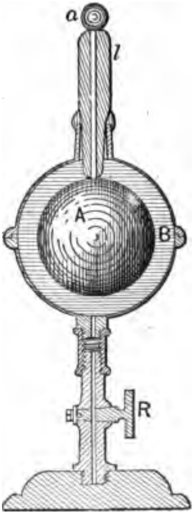

FIG. 102.—FARADAY'S APPARATUS FOR MEASURING SPECIFIC INDUCTIVE CAPACITY.

While the conductor *A B*, shown in Fig. 99, is under the influence of the positively charged body *C*, it will part with its positive charge on being touched by an earth-connected body, but will retain its negative charge, no matter at what point it is touched.

It retains its negative charge because this charge is held or maintained on the surface of *A*, by the attraction of the opposite positive charge on *B*. A charge in this condition is called a *bound* charge, in order to distinguish it from a *free* charge, or a charge situated on the surface of a body placed at so considerable a distance from any other body as to practically free it from its influence.

In order to discharge a bound charge it is necessary to simultaneously connect the two opposite charges by means of a conductor. A bound charge was formerly known as dissimulated or latent electricity.

That very important piece of electrical apparatus known as the Leyden jar, depends for its operation on the action of electrical induction and bound charges.

The discovery of the Leyden jar was made by Von Kleist in 1745. With a view of fixing electricity on an insulated substance, Von Kleist led the electricity into a glass bottle containing mercury by means of a brass wire attached to the conductor of an electric machine.

"As soon," he says, "as this little glass with the pin is removed from the electrical machine, a flaming pencil issues from it so long that I have been able to walk sixty paces in the room with this little burning machine; and, if the finger, or a piece of money, be held against the electrified pin, the stroke coming out is so strong that both arms and shoulders are shaken thereby."

The discovery of the Leyden jar produced an intense excitement throughout the scientific world.

Tiberius Cavallo, in a work on electricity published in 1795, speaks as follows about the discovery of the Leyden jar:

> Since the time of this discovery the prodigious number of Electricians, experiments and new facts that have been daily produced from every corner of Europe and other parts of the world is almost incredible. Discoveries crouded upon discoveries; improvements upon improvements, and the science ever since that time went on with so rapid a course, and is now spreading so amazingly fast, that it seems as if the subject would soon be exhausted, and Electricians would arrive at the end of their researches; but, however, the *ne plus ultra* is, in all probability, as yet at a great distance, and the young Electrician has a vast field before him highly deserving his attention and promising further discoveries, perhaps equal, or more important than those already made.

The Leyden jar consists essentially of two conductors placed near each other, but separated by a good dielectric. Under these circumstances a bound charge is produced by induction through the dielectric on the surfaces of the two plates, when one of the coatings is connected with the positive conductor of an electric machine, and the other coating is connected with the ground.

The form generally given to the Leyden jar is shown in Fig. 103, in which two metallic coatings are placed opposite each other on the outside and inside respectively of a glass jar.

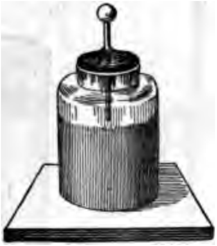

FIG. 103. - LEYDEN JAR.

The metal coatings should not extend to more than about two-thirds the height of the glass jar. In order to avoid a loss of the charge by the electricity creeping over the surface in damp weather, the uncoated part of the jar should be coated with shellac varnish.

The inner coating of the jar is generally connected to the knob by means of a metallic chain, which passes through an opening in a cork or wooden block secured to the mouth of the jar. This manner of supporting the knob and chain connected to the inner coating is, however, very objectionable, since in damp weather, even though the bare glass of the jar be covered by shellac varnish, the damp wood or cork block, which is in direct connection with the glass, permits a leakage of the charge.

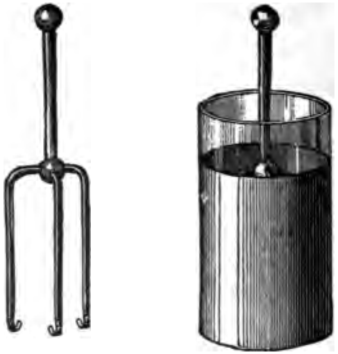

FIG. 104.—SIR WILLIAM THOMSON'S FORM OF LEYDEN JAR.

In order to overcome this difficulty Sir William Thomson devised the form of jar shown in Fig. 104. Here the knob is supported on three feet, which rest against the inner coating, and, in this way, the uncoated part of the glass, which as usual is covered with shellac varnish, can be readily dried and cleaned.

In some electrical apparatus the inner coating of the Leyden jar is formed by a layer of sulphuric acid, which serves the double purpose of acting as a coating and of keeping the inside of the jar dry by absorbing the moisture of the air.

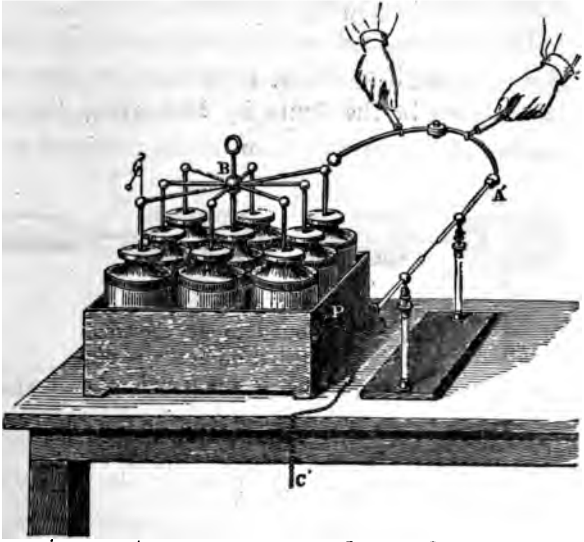

FIG. 105.—A BATTERY OF LEYDEN JARS.

Where it is desired to obtain a more powerful discharge than that furnished by a single jar, a number of separate jars have all their inner coatings con-

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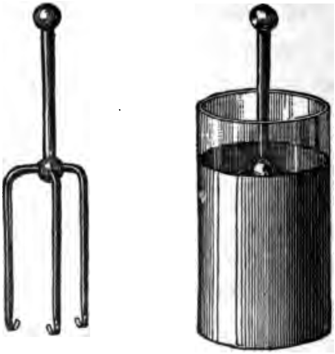

Fig. 104.—Sir William Thomson's Form of Leyden Jar.

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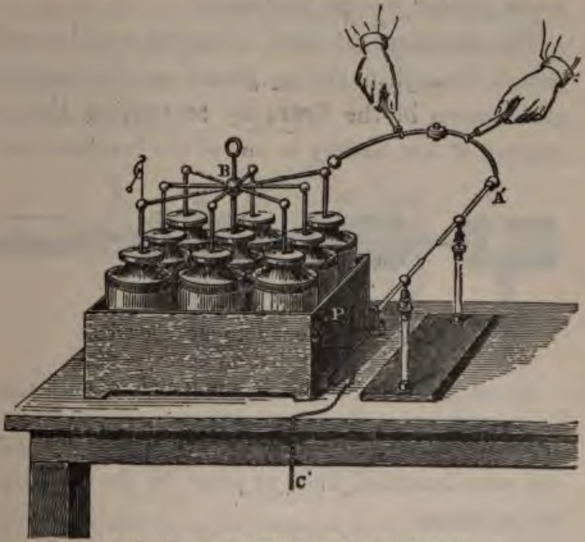

FIG. 105.—A BATTERY OF LEYDEN JARS.

Where it is desired to obtain a more powerful discharge than that furnished by a single jar, a number of separate jars have all their inner coatings connected together to form a single large inner coating, and all their outer coatings similarly connected to form a single large outer coating, the separate jars forming one large jar, or Leyden battery as shown in Fig. 105. Under these circumstances a charge of much greater volume is obtained.

The discharge of such a battery may be readily passed through anything placed on the insulating table shown in the figure by connecting the outer coating of the battery to one of the insulated points or knobs by a conductor, and the inner coating to the other insulated knob or point by the discharging rod as shown.

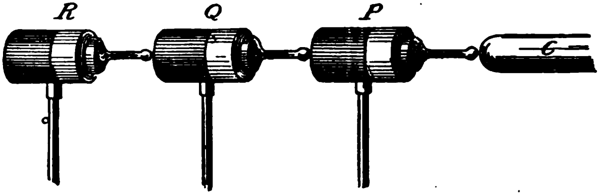

FIG. 106.—SERIES OR CASCADE CHARGING OF LEYDEN JARS.

When it is desired to obtain a discharge of greater jumping power or difference of potential than that obtained with the jars connected as above, the jars may be connected in cascade, or, as it is more commonly called, in series, in which case the inner coating of the first jar is connected to the outer coating of the second, and the inner coating of the second to the outer coating of the third, and so on as shown in Fig. 106.

Jars, so charged, may be discharged either in series or in multiple. In this latter case all the inner coatings are first connected together to form a single inner coating, and all the outer coatings are similarly connected together to form a single outer coating, before discharging.

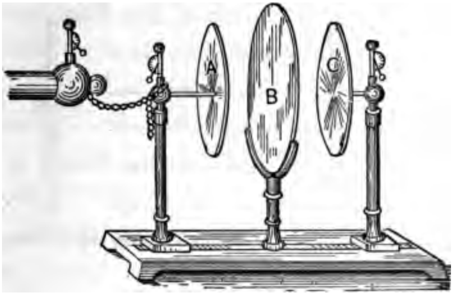

FIG. 107.—PLATE CONDENSER.

The discharge of a Leyden jar does not consist of a single disruptive discharge, but of a number of partial discharges and recharges which produce true oscillatory or surging discharges. This peculiarity of the discharge was first discovered by Prof. Joseph Henry.

A Leyden jar possesses a much greater capacity for receiving an electric charge than would a single conductor isolated from other conductors. It is for this reason that such an apparatus is often called a condenser.

Were the conducting plate *A*, Fig. 107, connected to the conductor of an electrical machine, without being placed near any other conductor, it would receive only a comparatively small charge; but, if placed near *C*, from which it is separated by a dielectric *B*, then, if *C*, is connected to the ground, the plate *A*, can receive a much greater charge; for, as *A*, receives a charge it produces by induction an opposite charge on that side of the plate *C*, which lies nearest to it, and repels a positive charge to the ground. The mutual attraction of these opposite charges practically leaves the plate *A*, free to receive a fresh charge from the machine.

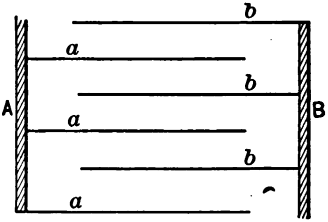

FIG. 108.—METHOD OF CONSTRUCTION OF A CONDENSER.

In reality the charge of a condenser resides on the opposite surfaces of the dielectric, as can be shown by means of a jar in which the coatings are readily separated from the glass.

Such a jar is called a dissected Leyden jar. It is usually made with metallic coatings of tin or other sheet metal, which fit closely to the outside and inside, respectively, of a dry glass jar. The inner coating is connected with a knob extending above the top of the glass jar. When the jar is charged, its three parts are then dissected or taken apart, when the metallic coatings can be safely handled. Even the glass jar can be touched on the outside or the inside without losing much of its charge. On putting the jar together again, the connection of its two coatings will produce a considerable discharge.

On dissecting the jar, after charging it, it is, of course, necessary to avoid simultaneously touching both coatings.

Condensers are employed in a variety of apparatus. In practice they are made of sheets of tinfoil *a*, *a*, *a*, and *b*, *b*, *b* (Fig. 108) connected to one another in two separate sets, by means of the metal bars *A* and *B*, respectively. The separate sheets of tin-foil are separated from one another by sheets of paraffined paper, or thin plates of mica.

The capacity of a condenser is measured in praccondition in a conductor. If the electrified cylinder have no conductor near it, but only air, which is an insulator, it cannot produce this induction, but can only produce a pressure or strain on the insulating medium due to the tendency to produce induction. The medium offers resistance to the electromotive force just as a table offers resistance to the fall by gravity of a weight. Putting the metal balls in the strained space relieves the strain and they suffer induction.

I will now show you one or two of the applications of this principle of induction. The first illustration is with the gold leaf electroscope. I rub my glass rod with silk. I bring it near the disc of the electroscope. The leaves diverge. The rod is positive. It attracts negative to the disc and repels positive to the gold leaves and causes them to diverge. I remove the glass rod. Induction ceases. The leaves collapse.

I now repeat the experiment in another way. Holding the rubbed glass as before near the disc of the electroscope, I touch the latter with my finger. The repelled positive condition passes through my body to the ground. The gold leaves are now negatively electrified and stand apart. I remove my finger and then the glass rod, and the leaves remain apart, being negatively electrified.

EXTRACTS FROM STANDARD WORKS.

The peculiarities of the phenomena attending electrostatic induction are thus described by Forbes in " A Course of Lectures on Electricity,"* page 16, delivered before the Society of Arts :

Here I have two large metal balls in contact, but each on an insulated stand of glass. Neither ball is electrified. Now, I take a glass cylinder and rub it with silk. It is now positively electrified. I touch the gold leaf electroscope with the electrified cylinder, and the leaves diverge with positive electrification. I now place the electrified glass cylinder close to one of the balls, but not touching. Now, the cylinder produces an electromotive force, attracting as it were negative electrification to the nearest ball, and repelling positive to the farther one. I take away the farthest ball and bring it near the disc of the gold leaf electroscope. The leaves diverge further, showing positive electrification. I now bring the other ball near it and the leaves collapse. The two balls have been electrified by induction, one positively, and the other negatively.

Thus we see that not only can an electrified body produce a visible effect in the way of motion on a material body, but it is also able to attract and repel the electrical condition in a conductor. If the electrified cylinder have no conductor near it, but only air, which is an insulator, it cannot produce this induction, but can only produce a pressure or strain on the insulating medium due to the tendency to produce induction. The medium offers resistance to the electromotive force just as a table offers resistance to the fall by gravity of a weight. Putting the metal balls in the strained space relieves the strain and they suffer induction.

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* "A Course of Lectures on Electricity, Delivered before the Society of Arts," by George Forbes. London: Longmans, Green & Co. 1888. 163 pages. 17 illustrations. Price, $1.50.

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XVI.—FRICTIONAL AND INFLUENCE MACHINES.

In order to readily produce electrical charges, various forms of frictional, or electrostatic influence machines are employed. A common form of such a machine, shown in Fig. 110, is known as the plate or frictional electrical machine.

The frictional electrical machine consists essentially of a plate *A*, of glass, supported on a horizontal axis, on which it can be readily rotated.

A rubber, formed of soft leather covered with an amalgam of tin and mercury, produces friction against the glass plate on the rotation of the plate. By this friction the glass becomes positively charged and the rubber negatively charged.

An insulated conductor *D*, called the positive or prime conductor, takes off or collects the charge from the glass plate, as the plate rotates between them, by means of a comb electrically connected to *D*, and furnished with metallic points placed on both sides of the plate. A smaller conductor, connected to the rubber by means of metallic plates placed on the outside of the rubber, receives a negative charge. This conductor is sometimes connected to the ground by means of a conducting wire or chain. Under these circumstances the sparks given off by the positive conductor are found to be larger.

Nearly all forms of frictional electrical machines are so dependent for their proper working on the condition of the air as regards the quantity of moisture present, and so readily either cease working entirely, or weaken on the approach of damp weather, that they have been almost entirely replaced by various forms of machines that depend for their action on electrostatic induction. This change has been hastened by the fact that induction machines are much more powerful than any form of frictional electrical machine that has yet been devised.

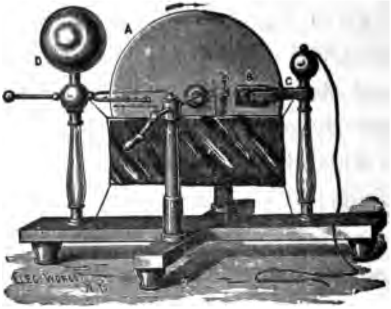

FIG. 110.—FRICTIONAL ELECTRICAL MACHINE.

To thoroughly understand the principles of operation of any form of influence machine, it will be necessary to study very carefully the construction and operation of a small form of induction machine called the electrophorus.

The electrophorus consists essentially of a disc of hard rubber or vulcanite *B*, Fig. 111, placed in a metallic form or dish. When briskly rubbed by a piece of cat's skin, the vulcanite becomes negatively charged. When, now, an insulated metallic disc *A*, is placed on the middle of the vulcanite disc, the negative charge in *B*, induces a positive charge on that side of *A*, which lies nearest *B*, and a negative charge on the side which lies furthest from *B*.

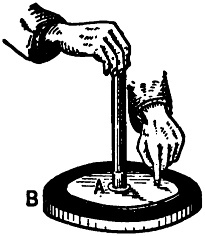

FIG. 111.—ELECTROPHORUS—CHARGING.

If, now, while in this condition, the disc *A*, be removed from *B*, by means of the insulated handle, no electrical effects will be present in it, since the two opposite and equal charges completely neutralize each other. If, however, the disc *A*, be first touched by the finger, or other earth-connected body, it will lose its free negative charge and retain its bound positive charge; and, if it then be raised or removed from the vulcanite disc, it will be found to possess a permanent positive charge, as can be shown by holding the knuckle to it, as shown in Fig. 112, when removed from the vulcanite disc.

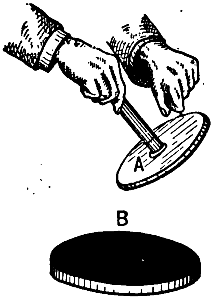

FIG. 112.—ELECTROPHORUS—DISCHARGING.

One of the commonest forms of electrostatic induction machines is seen in the well-known **Holtz machine** shown in Fig. 113.

The Holtz electrostatic induction machine consists of the following parts:

(1.) A stationary glass plate *A*, fixed at its edges to insulated supports.

(2.) A movable plate *B*, supported on an axis so as to be capable of rapid rotation.

(3.) Pieces of varnished paper *f*, *f′*, called armatures, placed on opposite sides of the fixed plate near poles or windows cut in the plate. The armatures are placed on the back of the fixed plate, that is, on the side furthest from the moving plate, so that, on rotation, the parts of the plate move toward tongues of varnished paper attached to the middle of the armature.

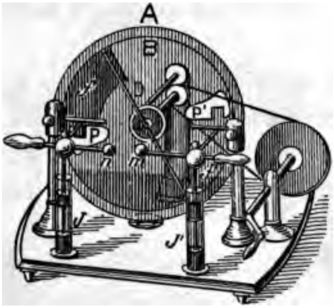

Fig. 113.—Holtz Induction Machine.

(4.) Metal combs *P*, *P′*, placed in front of the movable plate and connected to brass conductors *n*, *m*, one of which is movable toward and from the other by means of a suitable supporting insulated handle connected therewith.

When a small initial charge is given to one of the armatures, by holding a plate of electrified vulcanite against it, and rotating the plate while the balls are in contact, as soon as the machine is charged and the balls are gradually separated, a torrent of sparks will continue to pass between them as long as the plate is rotated.

If the balls are separated too far, the machine will lose its charge. The balls must then again be brought into contact and again gradually separated as before.

The Holtz machine is, in reality, a species of revolving electrophorus. It differs from an electrophorus mainly in that it is provided with means for constantly charging, discharging and recharging the movable plate.

The Holtz machine gives excellent results in action, but is sometimes difficult to start during damp weather.

A modification of the Holtz machine, which gives much better results, and which, approximately speaking, is independent of the condition of the air as regards moisture, is seen in the Wimshurst machine.

This form of machine is shown in Fig. 114.

Its construction is as follows: Two shellac-covered glass plates are placed, and supported as shown, so as to be capable of rapid rotation in opposite directions.

Thin metallic strips are placed on the outside of each of the glass plates, in the radial positions shown. These strips act as inductors and carriers, the carriers of one plate acting as inductors to the other plate.

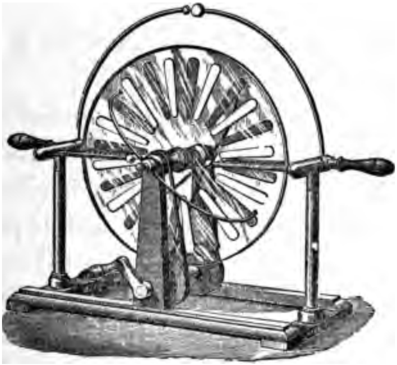

FIG. 114.—WIMSHURST MACHINE.

Two curved brass rods, terminating in fine wire brushes, that rest lightly against the plates, are placed at right angles to each other, one at the front of the plate and one at the back. Pairs of conductors, connected together, provided with collecting points, are placed in a horizontal position diametrically opposite each other, as shown. Sliding conductors, terminated with metallic balls, for discharging the conductors are provided, and extending over the top of the plate, as shown. Leyden jars, the inner coatings of which are connected with the two discharging rods, and the outer coatings are connected together, may be employed, as in the Holtz machine.

The exact action of this machine is not thoroughly understood.

In order to account for the production of electricity various theories or hypotheses have been proposed. We will discuss the more important of the older hypotheses; for, although such hypotheses are no longer believed in, yet references to them are to be found in almost all electrical literature, and it will, therefore, be necessary to have some ideas concerning them.

The two most prominent of these hypotheses are called respectively the single-fluid hypothesis of Franklin, and the double-fluid hypothesis of Du Fay.

The single-fluid hypothesis of Franklin endeavors to account for the cause of electrical phenomena by an assumption of the existence of a single electrical fluid.

The single-fluid hypothesis assumes:

(1.) That the phenomena of electricity are due to the presence of a *single,* tenuous, imponderable fluid.

The particles of this fluid mutually repel one another, but are attracted by all matter.

(2.) That every substance possesses a definite capacity for holding the assumed electrical fluid, and that when just this quantity is present, no electrical effects are manifested.

(3.) That when the body has less than this quantity present, it becomes negatively excited, and when it has more, it becomes positively excited.

(4.) That the act of electrification, as, for example, by friction, causes a redistribution of the fluid, part of it going to one of the bodies, giving it a surplus, and thus positively electrifying it, and leaving the other body with a deficit, thus negatively electrifying it.

The double-fluid hypothesis of Du Fay assumes :

(1.) That the phenomena of electricity are due to the presence of *two* imponderable fluids, a positive and a negative fluid.

(2.) That the particles of the positive fluid repel one another, as do also the particles of the negative fluid ; but that the particles of the positive fluid attract the particles of the negative and *vice versa.*

(3.) That the two fluids are strongly attracted by matter, and, when either is alone present, produces electrification ; but that when both are present in equal quantities, they unite and mask or neutralize each other.

(4.) That the act of electrification, as, for example, by friction, separates these fluids, one going to the rubber and the other to the thing rubbed.

Although neither the single nor the double fluid hypothesis is now accepted, yet it is recognized that, perhaps, the single-fluid hypothesis comes nearer to explaining most of the phenomena of electricity, with possibly this modification, that a negatively excited body is the one which possesses the excess of the assumed fluid, and a positively excited body the one which possesses the deficit.

According to another view, electricity is the same as the luminiferous ether. Electromotive force, or the force which causes electricity to move, results from differences in the ether pressures. One phase of electrification is assumed to result from a surplusage of energy, and the opposite phase from a deficit of energy.

At the present time, scientific men almost universally accept the theory of Hertz concerning what are called electromagnetic waves or radiations. A disruptive discharge, as has long been known, consists of a number of separate discharges that rapidly alternate, or change in direction.

According to Hertz's theory, disruptive discharges produce expanding lines of magnetic force that move outward from the surface of the conductor, in the shape of waves or radiations in the ether, surrounding and penetrating the conductor. In this way electromagnetic waves are produced in the ether, moving in all directions from the conductor with the velocity of light, and, in reality, differing from light only in that in most cases their wave lengths are much greater, and that, therefore, they follow one another much more slowly than do the waves which produce ordinary light.

Electrical currents, while changing their direction or intensity, also produce, as is well known, magnetic fields that expand and contract, and thus also produce electromagnetic waves or radiations the same as a spark or Leyden jar discharge.

Hertz has shown the actual presence of such electromagnetic waves or vibrations by causing them to excite similar vibrations in neighboring conductors by the well-known principles of resonance.

The principles of acoustic resonance are briefly as follows: If the dimensions and the elasticity of a body are such that a vibration of a definite rate or wave length can be produced in it, such vibration may be produced or excited in such body by means of sound waves in the air around it, provided the length of such waves be exactly the same as those the body is capable of producing. The excited waves may be produced in a body separated many feet from the exciting body, provided a medium such as the air connects them.

In the case of sound waves, this connecting medium is the air; in the case of electromagnetic waves, it is the universal ether. As in the case of acoustic resonance, the dimensions and elasticity of the body in which electromagnetic waves are produced by resonance must be such as will permit it to produce waves of the same wave length as those produced by the exciting body.

Hertz has clearly proved the existence of nodes in conductors through which surging discharges are passing.

Just in what manner a charge of electricity can be connected with the universal ether, or with the radiations produced by its discharge, is not yet apparent. It is probable, however, that this will be clearly recognized in the near future.

EXTRACTS FROM STANDARD WORKS.

Concerning the supposed duality of electrical phenomena, or the dual nature of electricity, Atkinson, in his "Elements of Static Electricity,"* page 40, says:

> We have already seen, in experiments with the pith ball electroscope, that the balls may be attracted and repelled by electrified glass, sealing wax, and various other substances.
>
> Let an electrified glass rod approach one of the balls; the ball is attracted, and, after contact, repelled. Now let an electrified stick of sealing-wax be brought near, and the electrified ball, which was repelled by the glass, is attracted by the wax. Or let the ball be first electrified and repelled by the wax, and it is attracted by the glass.
>
> Further experiments show that the same results can be produced with other substances, glass representing a certain class of substances, which show similar electrification, and sealing-wax and resin another class, which show opposite electrification to that of glass.
>
> Hence it has been assumed that there are two kinds of electricity—one kind generated on the class of substances represented by glass, and the other on the class represented by resin. The former was once designated as *vitreous*, and

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* "Elements of Static Electricity: with a Full Description of the Holtz and Töpler Machines and Their Mode of Operating," by Philip Atkinson. New York: The W. J. Johnston Company, Limited. 1887. 228 pages, 64 illustrations. Price, $1.50.

the latter as *resinous*; but the term *positive* is now used instead of vitreous, and *negative* instead of resinous. Used in this way, these terms have no reference to a difference either in quantity or intensity; they express only a supposed difference in *kind*, not in *degree*.

This doctrine of the dual nature of electricity was first proposed by Du Fay, and has since been maintained by many eminent scientists. Deschanel, speaking of the phenomena under consideration, says: "These phenomena clearly show that the electricity developed on the resin is not of the same kind as the electricity developed on the glass."

Now, the only thing "*clearly shown*" is the difference in the *substances*, not in the *electricity*. For we have precisely the same electric phenomena of attraction and repulsion with the glass as with the sealing-wax; but a third substance, the electrified pith ball, is attracted by one and repelled by the other; a result which it would seem more reasonable to attribute to the difference *known* to exist between the *substances*, than to a difference *supposed* to exist in the electricity. For it has already been shown that different causes, as conductivity or resistance, influence the intensity of electrification on different substances. Other causes also, as a difference of temperature or mass, or hardness or softness, density or porosity, doubtless contribute to the same result.

But considering the quality of resistance alone, the potential of any non-conductor, as glass, is liable to vary greatly on different parts of the surface when electrified by friction; and to differ from the potential of sealing-wax, similarly produced on different parts of *its* surface.

XVII.—ATMOSPHERIC ELECTRICITY.

There is always free electricity in the atmosphere, which, at different times, varies both in amount and in kind.

The identity of the lightning flash and the electric discharge was established by Franklin, by means of the classic kite, which he raised in Philadelphia in June, 1752, during the progress of a thunder storm. This kite was constructed like an ordinary kite except that it was covered with silk instead of paper, so as to withstand the rain, and was provided with a sharp point of iron extending about a foot or so above the top of the kite.

The kite was raised by means of ordinary pack thread. When sufficiently high in the air a key was suspended to the end of the thread, which was then insulated by means of a silk thread tied to a tree. On approaching the hand to the key during the thunder storm, no sparks or other electrical disturbances were obtained because the thread was a non-conductor of electricity. At last, however, rain fell, and the wet thread becoming a conductor, the experimenter succeeded in drawing sparks from the key, or, quoting Franklin: "At this key the phial may be charged; and from electric fire thus obtained, spirits may be kindled, and all other electrical experiments be performed, which are generally done by the help of a rubbed glass tube, and thereby the sameness of the electric matter with that of lightning completely demonstrated."

The following are among the more important facts that have been discovered concerning the free electricity of the atmosphere:

(1.) The free electricity of the atmosphere is generally positive, but frequently changes to negative on the approach of fogs or clouds.

(2.) It exists in greater quantity in the higher regions of the atmosphere than near the surface of the earth.

(3.) It is stronger when the air is still than when the wind is blowing.

(4.) It undergoes marked variations in its intensity, generally becoming stronger during winter than summer, and during the middle of the day and the early morning than at night.

The exact causes which produce the free electricity of the atmosphere are unknown. The following have been suggested as the causes of the free electricity of the atmosphere, viz.;

(1.) To the evaporation of water.

A certain difference of potential is invariably produced by the evaporation of water. When water, which has a small quantity of salt in solution, is evaporated, the vapor which rises becomes positively charged, while the solution remains negatively charged.

Since the waters of the ocean are constantly undergoing evaporation, this is probably one of the chief causes of the free electricity of the atmosphere.

(2.) The friction of the wind against the earth, or the friction of particles of air against one another or against particles of water.

Although this theory seems probable, yet it has been noticed that a smaller quantity of free electricity exists in the air when there is no wind, than when a strong wind is blowing.

(3.) The motion of terrestrial bodies through the magnetic field of the earth.

A conductor moving through a magnetic field has differences of potential produced in it. Such motion has, therefore, been suggested as one of the causes of free atmospheric electricity.

(4.) Differences of temperature.

Differences of temperature may produce thermo-electricity. Such differences have therefore been suggested as a possible cause of the free electricity of the atmosphere.

(5.) The combustion or gradual oxidation of animal matter.

Chemical action, or gradual oxidation or combustion, is the chief cause of the electricity produced in the voltaic pile. Chemical action, therefore, has been suggested as one of the causes which produce the free electricity of the atmosphere.

(6.) To the induction produced by the electrified sun or other heavenly body.

(7.) To induction from a negatively charged earth.

Some experiments by Crookes show that a charged body can retain its charge for an indefinite time, if the body is placed in a very high vacuum. It has, therefore, been suggested that since the earth moves through empty space around the sun, if it became charged in any manner it would necessarily retain such charge indefinitely. According to this conception, the electrical phenomena of the earth are due rather to the varying distribution of electric charges than to the production of fresh charges.

Although the chief cause of the production of electricity is presumably the evaporation of water, yet, probably, all the other named causes are not without their influence in such production.

The free electricity of the atmosphere produces a variety of effects. The principal of those which occur in the lower regions of the atmosphere, are lightning and the St. Elmo's fire. The principal effect which occurs in the upper regions of the atmosphere is the aurora.

The lightning flash is caused by a disruptive discharge which occurs between a charged cloud and the earth, or between neighboring clouds, whenever the difference of potential is sufficiently great.

The resulting thunder is due to a disturbance in the air caused to some extent directly by the passage of the discharge through the air, but mainly by the vacuum produced by the sudden condensation of the vapor formed by the passage of the discharge through rain drops.

Since lightning flashes are often several miles in length, the difference of potential must be enormous.

The manner in which such differences of potential are produced is probably as follows :

As the clouds move through the air, they collect the free electricity on the surfaces of the minute drops of water of which they are composed. When many thousands of these drops subsequently collect in a single drop, the difference of potential is enormously increased in consequence of the equally enormous decrease in the surface of any single drop over the sum of the surfaces of the thousands of minute drops that have coalesced to form such single drop.

That the potential which causes the lightning flash is brought about in this manner appears to be rendered probable by the following facts, which have been noticed concerning the geographical distribution of thunder storms.

(1.) Thunder storms seldom, if ever, occur in the polar regions. This is, probably, because the rain in the polar regions is caused by a condensation of the vapor which was evaporated in regions near the equator.

(2.) Thunder storms seldom, if ever, occur in rainless districts, owing, probably, to the absence of the condensation of vapor.

(3.) Thunder storms are most frequent and violent in the equatorial regions, where the rainfall results from the condensation of the vapor by the action of ascending currents conveying the vapor to the upper and colder regions of the atmosphere almost immediately after its formation into vapor.

(4.) In regions beyond the tropics thunder storms occur mainly at the season of the year when the rainfall comes from the vapor that is condensed shortly after the time of its formation.

A powerful lightning discharge produces a variety of well-known disastrous effects; it often shatters buildings, fuses metals or other conductors by the heating effect it produces as it passes through them, and often causes practically instantaneous death when the full discharge is passed through the bodies of men or other animals.

There are five varieties of lightning:

(1.) Zigzag, or forked lightning. Though apparently zigzag, this form in reality takes the shape of short curves, as has been shown by photographic pictures of the flash.

(2.) Sheet lightning, which appears as an expanded flash illumining the outlines of the clouds.

(3.) Heat lightning, or lightning without thunder. This variety, which is often seen near the horizon during clear, hot weather, is probably due to the reflection of the light from a lightning discharge accompanying a storm that is too far below the horizon to permit the thunder to be heard. According to some, however, such lightning is due to the passage of electricity through highly rarefied air.

(4.) Volcanic lightning, or that observed around the craters of volcanoes during their eruption. This form is probably caused by the rapid condensation of the water vapor emitted from the crater during an eruption.

(5.) Globular lightning, a rare form in which the lightning appears as a globe of light, which either remains stationary in the air or moves slowly through it.

The lightning rod, an invention of Franklin, consists essentially of an electrical conductor attached to the side of the building to be protected and extending above the highest parts of the building. Its lower end is placed in good electrical connection with the earth. In order to insure the proper operation of a lightning rod in protecting a building, the following conditions must be carefully obtained; viz.,

(1.) The rod must have such an area of cross section as to enable it to carry to the earth without fusing the greatest discharge that it is likely to receive.

(2.) The rod must be continuous throughout; if joints are used, care must be taken to make their resistance as low as possible, and to protect them against corrosion.

(3.) The rod should terminate at its upper extremity in one or more points formed of some non-corrodible metal, such as platinum or nickel.

(4.) The lower end of the rod should be carried into earth until it meets permanently moist or damp ground, where it should be attached to metal plates, or to the gas or water pipes, by wrapping it around and soldering it to such pipes.

Unless a thorough ground is obtained, a lightning rod is worse than useless, no matter how carefully every other part has been constructed ; for, if a discharge strikes a rod that is imperfectly grounded, it is almost certain to destroy the building to which the rod is attached.

(5.) According to some practice, it is a matter of indifference whether or not the rod is insulated from the building. It should not, however, pass down the wall of a building in the immediate neighborhood of gas or water pipes on the opposite side of the wall. According to some, the top should always be insulated from the building.

(6.) The rod should project above the highest part of the building. A rod will protect a conical space around it whose base is equal to the vertical height of the rod above the ground, but whose sides are curved inward instead of being straight.

A lightning rod sometimes fails to protect a building because an ascending current of heated air from a fire in the house, or from the gradual heating of green hay or grain in a barn, increases the virtual height of a building beyond the ability of the rod to protect it.

(7.) The rod should preferably be of flat section, or be formed of stranded conductors, rather than of a single, solid conductor.

Two different kinds of lightning discharges occur, that is, the discharge of a charged cloud to the earth or to a neighboring cloud may occur in two distinct ways, viz.:

(1) As a steady strain or current.

(2.) As an impulsive rush or oscillatory discharge.

Discharge by a steady strain or current occurs either when the cloud gradually approaches a point on the earth, or when the cloud receives its charge gradually by the approach of another cloud.

In a steady discharge, the lightning rod, with its pointed end, either quietly discharges the cloud by a convective discharge, or by a harmless conductive discharge through the rod, after a spark has passed disruptively between the cloud and the rod.

The impulsive discharge or rush occurs whenever the cloud that discharges to the earth receives its charge suddenly, as by the discharge of a neighboring cloud; or, when a bound charge, produced by the presence of a neighboring charged cloud, is suddenly liberated by discharge, and, thus becoming free, impulsively discharges to the earth.

In an impulsive discharge or rush, a counter-electromotive force is set up in the rod, which resists the passage of the discharge through the rod and causes the electricity to rush back and spit off in lateral discharges. In this case the conducting power of the rod has no effect in facilitating the discharge.

Tall objects are especially liable to receive lightning strokes because the discharge occurs between points of greatest difference of potential, and such points will naturally be situated between the cloud and the nearest object connected to the earth.

Ships at sea are, therefore, especially liable to lightning strokes, and, before the application of the system of lightning protection devised by Harris, many vessels were destroyed by such discharges.

In Harris' system of lightning protection for ships the lightning rods are formed of plates and rods so placed on the masts as to readily yield to strains. Harris grounded the rods by connecting them with the copper sheathing of the vessel. He also connected the rods with all masses of metal in the ship. The latter protection was especially necessary in the case of men-of-war to protect the powder magazines.

Harris' system of lightning protection for ships was adopted only after considerable opposition. It proved, however, so efficacious in practice that serious effects of lightning on vessels so protected are now almost unknown. In 1845, Harris received the honor of knighthood from the English government for his services in this direction.

Lightning discharges often occasion considerable damage to instruments connected to aërial lines of conductors, such as those employed for telegraphic or telephonic communication, or for electric motors and dynamo-electric machines. In order to protect the instruments from such destructive discharges, some form of lightning arrester is employed.

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The oscillatory character of the discharge of a lightning flash permits such discharge to take, by preference, a path to the ground through the air space that lies between the points on the plates and the earth-connected plate *G*, rather than through the intruments connected to *C* and *D*.

Tongues of faintly luminous fire are sometimes seen on dark nights at the pointed ends of earth-connected bodies, such, for example, as the tops of church steeples, or the masts of ships. These are called St. Elmo's fires and are due to convective discharges. They are called by sailors *corposants*.

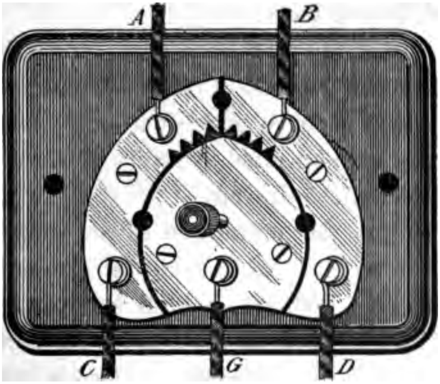

FIG. 115.—COMB LIGHTNING ARRESTER.

Another phenomenon due to the presence of free electricity in the atmosphere, but limited to the higher regions of the atmosphere, is seen in the aurora, which in the Northern Hemisphere is known as the aurora borealis. In this phenomenon, sheets, columns, arches, or pillars of faintly luminous light, generally of a reddish color, appear. Although their exact cause is unknown, yet it would appear beyond any reasonable doubt that they are due to the passage of electrical discharges through the upper and rarer regions of the atmosphere. This conclusion is based on the following facts:

(1.) During the prevalence of an aurora there exists an unusual quantity of free electricity in the air. This excess is often so great that long lines of telegraph have been operated by means of the electricity taken directly from the air.

(2.) During the prevalence of an aurora, there exist well marked earth currents. Differences of potential are produced in different parts of the earth, which result in currents called earth currents. These currents often cause considerable trouble to telegraphers. They enter the telegraph lines from the ground plates. Probably a greater disturbance in the telegraph lines is due to this cause than to the free electricity in the air.

(3.) The presence of an aurora is frequently accompanied by magnetic storms, during which the earth's magnetism undergoes considerable variations.

The auroral light, when examined spectroscopically, gives a spectrum characteristic of a luminous gaseous matter that, according to S. P. Thompson, is produced by matter that is not referable with certainty to any substance on the earth.

It is believed by some that the intermittent character of the flashes of light is due to the discharge being influenced by the earth's magnetism.

Whatever may be the exact cause of auroras, their appearance can be very closely reproduced by the passage of electrical discharges through vacuous spaces contained in Geissler or other similar tubes.

Geissler tubes consist of vacuous tubes of glass provided with platinum electrodes passed through and fused into the glass. They are used for obtaining luminous effects by passing the discharge from induction coils or electric machines through them.

Geissler tubes are made of a great variety of shapes and often include tubes, spirals, spheres, etc., within other tubes. These inclosed tubes are made either of ordinary glass, or of uranium glass, in order to obtain the effects of fluorescence. Some of the many forms of Geissler tubes are shown in Fig. 116.

It is generally supposed that the vacuum in a Geissler tube is a very high vacuum. This is not the case. The vacuum is by no means a high key, or, quoting Franklin: "At this key the phial may be charged; and from electric fire thus obtained, spirits may be kindled, and all other electrical experiments be performed, which are generally done by the help of a rubbed glass tube, and thereby the sameness of the electric matter with that of lightning completely demonstrated."

The following are among the more important facts that have been discovered concerning the free electricity of the atmosphere:

(1.) The free electricity of the atmosphere is generally positive, but frequently changes to negative on the approach of fogs or clouds.

(2.) It exists in greater quantity in the higher regions of the atmosphere than near the surface of the earth.

(3.) It is stronger when the air is still than when the wind is blowing.

(4.) It undergoes marked variations in its intensity, generally becoming stronger during winter than summer, and during the middle of the day and the early morning than at night.

The exact causes which produce the free electricity of the atmosphere are unknown. The following have been suggested as the causes of the free electricity of the atmosphere, viz.;

(1.) To the evaporation of water.

A certain difference of potential is invariably produced by the evaporation of water. When water, which has a small quantity of salt in solution, is evaporated, the vapor which rises becomes positively charged, while the solution remains negatively charged.

Since the waters of the ocean are constantly undergoing evaporation, this is probably one of the chief causes of the free electricity of the atmosphere.

(2.) The friction of the wind against the earth, or the friction of particles of air against one another or against particles of water.

Although this theory seems probable, yet it has been noticed that a smaller quantity of free electricity exists in the air when there is no wind, than when a strong wind is blowing.

(3.) The motion of terrestrial bodies through the magnetic field of the earth.

A conductor moving through a magnetic field has differences of potential produced in it. Such motion has, therefore, been suggested as one of the causes of free atmospheric electricity.

(4.) Differences of temperature.

Differences of temperature may produce thermo-electricity. Such differences have therefore been suggested as a possible cause of the free electricity of the atmosphere.

(5.) The combustion or gradual oxidation of animal matter.

Chemical action, or gradual oxidation or combustion, is the chief cause of the electricity produced in the voltaic pile. Chemical action, therefore, has been suggested as one of the causes which produce the free electricity of the atmosphere.

(6.) To the induction produced by the electrified sun or other heavenly body.

(7.) To induction from a negatively charged earth.

Some experiments by Crookes show that a charged body can retain its charge for an indefinite time, if the body is placed in a very high vacuum. It has, therefore, been suggested that since the earth moves through empty space around the sun, if it became charged in any manner it would necessarily retain such charge indefinitely. According to this conception, the electrical phenomena of the earth are due rather to the varying distribution of electric charges than to the production of fresh charges.

Although the chief cause of the production of electricity is presumably the evaporation of water, yet, probably, all the other named causes are not without their influence in such production.

The free electricity of the atmosphere produces a variety of effects. The principal of those which occur in the lower regions of the atmosphere, are lightning and the St. Elmo's fire. The principal effect which occurs in the upper regions of the atmosphere is the aurora.

The lightning flash is caused by a disruptive discharge which occurs between a charged cloud and the earth, or between neighboring clouds, whenever the difference of potential is sufficiently great.

The resulting thunder is due to a disturbance in the air caused to some extent directly by the passage of the discharge through the air, but mainly by the vacuum produced by the sudden condensation of the vapor formed by the passage of the discharge through rain drops.

Since lightning flashes are often several miles in length, the difference of potential must be enormous.

The manner in which such differences of potential are produced is probably as follows :

As the clouds move through the air, they collect the free electricity on the surfaces of the minute drops of water of which they are composed. When many thousands of these drops subsequently collect in a single drop, the difference of potential is enormously increased in consequence of the equally enormous decrease in the surface of any single drop over the sum of the surfaces of the thousands of minute drops that have coalesced to form such single drop.

That the potential which causes the lightning flash is brought about in this manner appears to be rendered probable by the following facts, which have been noticed concerning the geographical distribution of thunder storms.

(1.) Thunder storms seldom, if ever, occur in the polar regions. This is, probably, because the rain in the polar regions is caused by a condensation of the vapor which was evaporated in regions near the equator.

(2.) Thunder storms seldom, if ever, occur in rainless districts, owing, probably, to the absence of the condensation of vapor.

(3.) Thunder storms are most frequent and violent in the equatorial regions, where the rainfall results from the condensation of the vapor by the action of ascending currents conveying the vapor to the upper and colder regions of the atmosphere almost immediately after its formation into vapor.

(4.) In regions beyond the tropics thunder storms occur mainly at the season of the year when the rainfall comes from the vapor that is condensed shortly after the time of its formation.

A powerful lightning discharge produces a variety of well-known disastrous effects; it often shatters buildings, fuses metals or other conductors by the heating effect it produces as it passes through them, and often causes practically instantaneous death when the full discharge is passed through the bodies of men or other animals.

There are five varieties of lightning:

(1.) Zigzag, or forked lightning. Though apparently zigzag, this form in reality takes the shape of short curves, as has been shown by photographic pictures of the flash.

(2.) Sheet lightning, which appears as an expanded flash illumining the outlines of the clouds.

(3.) Heat lightning, or lightning without thunder. This variety, which is often seen near the horizon during clear, hot weather, is probably due to the reflection of the light from a lightning discharge accompanying a storm that is too far below the horizon to permit the thunder to be heard. According to some, however, such lightning is due to the passage of electricity through highly rarefied air.

(4.) Volcanic lightning, or that observed around the craters of volcanoes during their eruption. This form is probably caused by the rapid condensation of the water vapor emitted from the crater during an eruption.

(5.) Globular lightning, a rare form in which the lightning appears as a globe of light, which either remains stationary in the air or moves slowly through it.

The lightning rod, an invention of Franklin, consists essentially of an electrical conductor attached to the side of the building to be protected and extending above the highest parts of the building. Its lower end is placed in good electrical connection with the earth. In order to insure the proper operation of a lightning rod in protecting a building, the following conditions must be carefully obtained; viz.,

(1.) The rod must have such an area of cross section as to enable it to carry to the earth without fusing the greatest discharge that it is likely to receive.

(2.) The rod must be continuous throughout; if joints are used, care must be taken to make their resistance as low as possible, and to protect them against corrosion.

(3.) The rod should terminate at its upper extremity in one or more points formed of some non-corrodible metal, such as platinum or nickel.

(4.) The lower end of the rod should be carried into earth until it meets permanently moist or damp ground, where it should be attached to metal plates, or to the gas or water pipes, by wrapping it around and soldering it to such pipes.

Unless a thorough ground is obtained, a lightning rod is worse than useless, no matter how carefully every other part has been constructed; for, if a discharge strikes a rod that is imperfectly grounded, it is almost certain to destroy the building to which the rod is attached.

(5.) According to some practice, it is a matter of indifference whether or not the rod is insulated from the building. It should not, however, pass down the wall of a building in the immediate neighborhood of gas or water pipes on the opposite side of the wall. According to some, the top should always be insulated from the building.

(6.) The rod should project above the highest part of the building. A rod will protect a conical space around it whose base is equal to the vertical height of the rod above the ground, but whose sides are curved inward instead of being straight.

A lightning rod sometimes fails to protect a building because an ascending current of heated air from a fire in the house, or from the gradual heating of green hay or grain in a barn, increases the virtual height of a building beyond the ability of the rod to protect it.

(7.) The rod should preferably be of flat section, or be formed of stranded conductors, rather than of a single, solid conductor.

Two different kinds of lightning discharges occur, that is, the discharge of a charged cloud to the earth or to a neighboring cloud may occur in two distinct ways, viz.:

(1) As a steady strain or current.

(2.) As an impulsive rush or oscillatory discharge.

Discharge by a steady strain or current occurs either when the cloud gradually approaches a point on the earth, or when the cloud receives its charge gradually by the approach of another cloud.

In a steady discharge, the lightning rod, with its pointed end, either quietly discharges the cloud by a convective discharge, or by a harmless conductive discharge through the rod, after a spark has passed disruptively between the cloud and the rod.

The impulsive discharge or rush occurs whenever the cloud that discharges to the earth receives its charge suddenly, as by the discharge of a neighboring cloud; or, when a bound charge, produced by the presence of a neighboring charged cloud, is suddenly liberated by discharge, and, thus becoming free, impulsively discharges to the earth.

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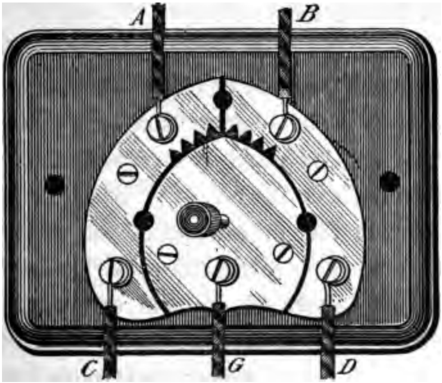

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It is generally supposed that the vacuum in a Geissler tube is a very high vacuum. This is not the case. The vacuum is by no means a high vacuum. Indeed, if the exhaustion of the tube is pushed too far, the luminous effects are considerably decreased.

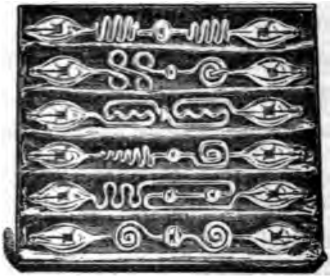

FIG. 116.—GEISSLER TUBES.

Auroras are very apt to accompany those unusual outbursts of solar activity called sun-spots. These are, therefore, in all probability, connected in some manner with the radiant energy of the sun. Magnetic storms are also the usual concomitants of sun-spots.

EXTRACTS FROM STANDARD WORKS.

In his "Elements of Physical Geography,"* page 111, the author thus describes some of the electrical phenomena of the atmosphere:

Electric excitement is always present in the atmosphere. The electricity of the air is generally positive, although it often changes rapidly to negative, on the approach of clouds or fogs. It is feeblest within a few feet of the surface, and increases with the elevation above the general surface of the earth.

Origin of Free Atmospheric Electricity—The electricity of the atmosphere is caused by a variety of circumstances, the chief of which are evaporation and condensation; unequal heating of the earth by the sun's rays; combustion; animal and vegetable life; and, possibly, the friction of winds against each other or against the earth's surface.

Lightning occurs when the electricity of a cloud discharges to the earth or to a neighboring cloud. The discharge is attended by a vivid spark, called lightning. The destructive effects of the lightning are due to the discharge between the clouds and the earth.

Thunder.—The heat of the spark vaporizes the rain drops, and enormously expands the air, producing on their subsequent cooling a partial vacuum, which is further increased by the momentary pushing aside of the air by the discharge. The surrounding air rushing violently into this vacuum produces the sound called thunder.

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* "Elements of Physical Geography, for the Use of Schools, Academies and Colleges," by Edwin J. Houston, A.M. Philadelphia: Eldredge & Brother, 1891. 172 pages. Revised Edition. Price $1.25.

The potential of the lightning flash is enormously higher than that produced by artificial means, and must be equal to many millions of volts. This high potential is due to the enormous decrease in the surface of a single raindrop from that of the thousands of smaller drops which have coalesced to form it.

Varieties of lightning.—There are five varieties of lightning: *zigzag* or *chain*, *sheet*, *heat*, *globular*, and *volcanic lightning.*

Zigzag lightning probably owes its forked shape to the resistance which the air offers to its passage through it. The air particles, being crowded together in the path of the spark, the lightning darts to one side, where the air is less dense.

Sheet lightning generally accompanies thunder storms and appears as an expanded flash, which illumines the clouds.

Heat lightning, or *lightning without thunder*, is generally seen near the horizon, during hot weather. It is probably caused by the reflection of lightning from a storm below the horizon.

Globular lightning.—On rare occasions the lightning appears in the form of a globe of light, which remains stationary in the air or moves slowly through it. Its cause is unknown.

Volcanic lightning.—During the eruption of volcanoes, vivid flashes of lightning often occur in the air near the craters. Volcanic lightning is probably caused by the rapid condensation of the vast volumes of vapor emitted with the ashes and lava.

Lightning rods, invented by Franklin, protect the buildings on which they are placed, by quietly discharging the electricity from the overhanging cloud. They generally effect this by an opposite electricity passing from the earth up the rod, and neutralizing that of the cloud. Unless the rods are placed in good metallic connection with the earth, and with all conductors near them, they are sources of danger rather than of protection.

Noad, in his book "The Student's Text-Book of Electricity,"* on page 114, speaks thus in reference to what atmospheric electricity is:

Is it electricity of the earth, or electricity of the air, or electricity of watery or other particles in the air?

Professor Thomson (*Proceedings of the Royal Institution*, May 18, 1860) does not agree with Peltier in regarding the earth as a resinously charged conductor insulated in space, and subject only to accidental influences from temporary electric deposits in clouds or air around it; because, although it is true that in severe weather the earth's surface is generally found to be negatively electrified, and although the earth is insulated in its atmospheric envelope, being in fact a conductor touched only by air (a strong insulator), it is to be remarked that air when highly rarefied becomes weak in its resistance to the transference of electricity through it, and begins to appear rather as a conductor than as an insulator, so that at a distance of 100 miles or upward from the earth's surface, the air in space cannot in all probability have resisting power enough to bear any such electric force as those which we find even in serene weather in the lower strata, and there must always be *essentially* in the higher aerial regions a distribution arising from the self-relief by the outer highly rarefied air by disruptive discharges.

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* "The Student's Text-Book of Electricity." by Henry M. Noad. London: Crosby, Lockwood & Co. 1879. 615 pages, 471 illustrations. Price, $4.00.

Thomson considers that this electric stratum must constitute very nearly the electropolar complement of all the electricity that exists on the earth's surface and in the lower strata of the atmosphere.

The quality of non-resistance to electric force of the thin interplanetary air being considered, the *earth*, the *atmosphere*, and the surrounding medium may be regarded as constituting respectively the *inner* coating, the *dielectric*, and the outer coating of a large Leyden phial charged *negatively*.

The methods employed for collecting atmospheric electricity (burning match, dropping water) give the "*electric potential*" of the air at the point occupied by the burnin match or by the portion of the stream of water where breaks into drops.

XVIII.—PRIMER OF PRIMERS.

The only fact known in electricity in the year 600 B. C. was that amber, when rubbed against the clothing, acquired the property of first attracting and then repelling light objects brought near to it.

There are two kinds of electricity; viz., positive and negative. A body charged with positive electricity will repel another body charged with positive electricity, but will attract a body charged with negative electricity.

An electroscope determines both the presence and the character of an electric charge. An electrometer measures the quantity of such charge.

Electrostatics treats of the properties and peculiarities of electric charges.

The laws of electrostatics may be expressed as follows, viz.:

(1.) Like charges repel one another, unlike charges attract.

(2.) The force exerted by the attraction or repulsion of two charges is directly proportional to the product of the quantities of electricity and inversely proportional to the square of the distance between them.

Substances differ in the ease with which electric excitement is transmitted through them. Some permit the electric force to be readily passed through them and are called conductors. Others resist the passage of the electric force and are called non conductors or insulators. The metals, well burned charcoal, and moist earth are conductors; oil, dry air, gas, wax, resin and hard rubber are non-conductors or insulators.

In order to insulate a wire or conductor, the insulating material is either spread over the surface of the wire or conductors or serves as a support on which such wire or conductor rests.

Both the insulating power and the tensile strength should be considered in selecting a material suitable for an insulator.

When the ends of several wires or conductors are joined together, the method employed in effecting such joint should not introduce an excessive resistance at the point of junction. Among the commonest forms of joints employed for telegraphic and telephonic wires are the American twist joint, the Britannia joint, and the parallel sleeve joint.

When an insulated conductor is electrified by friction, or by contact with another electrified body, it receives what is known as an electric charge. When a charged body is so placed that its charge can be transferred to another body, or to the earth, it will lose its charge or be discharged. An electric discharge produces an electric current.

The electric discharge produces a variety of effects which can be conveniently arranged under the following heads :

(1.) Mechanical effects.
(2.) Thermal or heating effects.
(3.) Luminous effects.
(4.) Magnetic effects.
(5.) Chemical effects.
(6.) Physiological effects.

An electric discharge can be effected in a variety of ways; among the most important of these are :

(1.) The conductive discharge, where the discharge is effected by means of a conducting path established between the charged body and the body to which the discharge is transferred.

(2.) The convective discharge, or that in which the discharge is effected at points that are electrically connected with the charged body by means of streams of electrified air particles that are thrown off from the points, and which gradually discharge the body by minute charges carried therefrom.

(3.) A disruptive discharge, in which the body which is to receive the charge is brought near to, but not in actual contact with, the charged body until the discharge passes by means of a spark through the air or other space separating the two bodies.

An electric source consists of any contrivance or combination of parts by means of which electric excitement can be obtained by the proper expenditure of energy.

The electricity produced by electric sources is passed through various electro-receptive devices, that are connected to the source by conducting circuits, and afterwards returns to the source.

The points of a source at which the electricity respectively leaves and enters it are called its poles; that point at which the current leaves the source being called its positive pole, and the point at which it enters the source, after it has passed through the receptive device, is called its negative pole.

The energy expended in operating an electric source is converted into electrical energy.

Electric sources are of a great variety of forms. They may be conveniently arranged into classes according to the character of the energy required to operate them.

Among electric sources by means of which mechanical energy or energy of motion is converted into electrical energy, are the frictional electric machine, the hydro-electric machine, the magneto-electric machine, and the dynamo-electric machine. Among those for converting the radiant energy of light or heat into electric energy, are the thermopile and various crystalline bodies like tourmaline. Among those for converting chemical potential energy into electric energy, are the voltaic cell and the charged storage battery.

Electro-receptive devices are means by which one or more of the effects produced by an electric discharge or current are obtained. They consist of various combinations of circuits in which various effects are produced when an electric discharge or current is passed through them.

The poles of an electro-receptive device [illegible] points where the current passes into and out of [illegible] device. The positive pole of an electro-receptive device is the pole connected with the positive [illegible] of the battery or electric source; the negative [illegible] of an electro-receptive device is the pole [illegible] with the negative terminal of the source [illegible] source. This usage is different from that adopted in the case of an electric source.

A great variety of electro-receptive devices have been devised ; in all, however, electric energy is converted into some other phase of energy, such, for example, as chemical energy, heat energy, luminous energy, or mechanical energy.

In some forms of electro-receptive devices the electric energy is converted into more than a single form of energy, such, for example, as the electric lamp, where light, heat and magnetic energy are produced.

Among some of the more important forms of electro-receptive devices are electric motors, arc and incandescent lamps, plating baths, uncharged storage batteries, transformers, Leyden jars or condensers, electromagnets, electric bells, electric annunciators, and various telegraphic and telephonic apparatus.

It is important to remember that an electric source should not be regarded as producing electricity or electric currents. What it produces is a difference of electric potential ; or, as it is commonly called, electromotive force.

When an electric source has produced a difference of potential or electromotive force at its terminals or poles, and these poles are connected by means of any conducting path, such difference of potential equalizes itself, and produces a discharge through such conducting path, or, in other words, causes an electric current to flow through it. The value of this current strength, in the case of steady currents, is directly proportional to the difference of potential or electromotive force, and inversely proportional to the resistance.

Differences of electric potential, or of electric level, may be regarded as similar to differences of liquid level. If a difference of liquid level exists between any two points in a vessel filled with liquid, and these two points are connected by an open tube, a current will be produced, and the liquid will flow through such tube from the higher to the lower level. The quantity of such flow will depend on the difference of level and the area of cross section of the tube.

Similarly, if a difference of electrical level or potential be obtained by means of an electric source, and any two points at different levels be connected by a conductor, an electric current will be produced which is assumed to flow from the higher to the lower level. The amount of such flow, in the case of steady currents, is directly proportional to the difference of level, and inversely proportional to the resistance. In all cases, the electricity produced by different sources as a result of difference of level, is assumed to flow from the higher to the lower level, or from the positive to the negative pole.

The electric current, or the rate of flow of electricity, between any two points, is conveniently expressed by the following formula:

$$C = \frac{E}{R}$$

in which C, equals the current strength; E, the electromotive force, and R, the resistance.

An electric circuit consists of an electric source or sources connected in a variety of ways with an electro-receptive device or devices by means of conducting paths.

Electric circuits are of a great variety of forms; in all, however, the current strength can be determined by means of the following formula, namely,

$$C = \frac{E}{r + r' + r''}$$

in which C, equals the current strength, E, the electromotive force, r, the resistance of the electric source, r', the resistance of the leads or conductors, and r'', the resistance of the electro-receptive devices.

The Centimetre-Gramme-Second system of units is based on the centimetre as the unit of length, the gramme as the unit of mass, and the second as the unit of time. The various measurements required in electrical work are based on the centimetre-gramme-second system of units. The value of such units, however, is inconvenient in practice and they have, therefore, been replaced by certain units called the practical electric units.

The practical electric units are as follows :

The practical unit of electric current is called the ampère, after Ampère. The ampère is such a rate of flow or transmission of electricity, as would pass through a circuit whose resistance is one ohm, when under an electromotive force of one volt.

Defined by the amount of chemical decomposition it can effect, the ampère is such a current as will deposit .00111815 gramme of silver per second, or .00009326 gramme of dilute sulphuric acid per second.

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The practical unit of electric pressure or of electromotive force is called the volt, after Alexander Volta. The volt is equal to the electromotive force required to cause a current of one ampère to pass through a circuit whose resistance is one ohm.

The practical unit of electric resistance is called the ohm, after Dr. Ohm. The ohm is such a resistance as would limit the flow of electricity through a circuit under an electromotive force of one volt to one ampère, or one-coulomb-per-second.

The ohm is a resistance equal to that of a column of mercury of about 106 centimetres in length and one square millimetre in area of cross section at the temperature of 0° C.

The practical unit of electric capacity is called the farad, after Michael Faraday. A farad is such a capacity of a conductor as would enable it to hold a quantity of electricity equal to one coulomb when put into it under a pressure of one volt.

The practical unit of electric work is called the joule, after Dr. Joule. A joule, or volt-coulomb, is equal to the product of a volt by an ampère.

The formula $C = \frac{E}{R}$ is an expression for what is known in science as Ohm's law. We may express the same thing as follows:

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There are three expressions for the watts or the volt-ampères; namely,

(1.) $C\,E =$ The watts.

(2.) $C^2\,R =$ The watts.

(3.) $\frac{E^2}{R} =$ The watts.

Various electric circuits are employed in the practical distribution of electricity. The most important of these are:

(1.) The series circuit.

(2.) The multiple circuit.

(3.) The multiple-series circuit.

(4.) The series-multiple circuit.

In the series connection of sources the positive pole of each separate source is connected to the negative pole of each succeeding source, and the negative and positive poles of the extreme ends are connected to conductors external to the battery. In proportional to the square of the distance between them.

Substances differ in the ease with which electric excitement is transmitted through them. Some permit the electric force to be readily passed through them and are called conductors. Others resist the passage of the electric force and are called non conductors or insulators. The metals, well burned charcoal, and moist earth are conductors; oil, dry air, gas, wax, resin and hard rubber are non-conductors or insulators.

In order to insulate a wire or conductor, the insulating material is either spread over the surface of the wire or conductors or serves as a support on which such wire or conductor rests.

Both the insulating power and the tensile strength should be considered in selecting a material suitable for an insulator.

When the ends of several wires or conductors are joined together, the method employed in effecting such joint should not introduce an excessive resistance at the point of junction. Among the commonest forms of joints employed for telegraphic and telephonic wires are the American twist joint, the Britannia joint, and the parallel sleeve joint.

When an insulated conductor is electrified by friction, or by contact with another electrified body, it receives what is known as an electric charge. When a charged body is so placed that its charge can be transferred to another body, or to the earth, it will lose its charge or be discharged. An electric discharge produces an electric current.

The electric discharge produces a variety of effects which can be conveniently arranged under the following heads :

(1.) Mechanical effects.
(2.) Thermal or heating effects.
(3.) Luminous effects.
(4.) Magnetic effects.
(5.) Chemical effects.
(6.) Physiological effects.

An electric discharge can be effected in a variety of ways ; among the most important of these are :

(1.) The conductive discharge, where the discharge is effected by means of a conducting path established between the charged body and the body to which the discharge is transferred.

(2.) The convective discharge, or that in which the discharge is effected at points that are electrically connected with the charged body by means of streams of electrified air particles that are thrown off from the points, and which gradually discharge the body by minute charges carried therefrom.

(3.) A disruptive discharge, in which the body which is to receive the charge is brought near to, but not in actual contact with, the charged body until the discharge passes by means of a spark through the air or other space separating the two bodies.

An electric source consists of any contrivance or combination of parts by means of which electric excitement can be obtained by the proper expenditure of energy..

The electricity produced by electric sources is passed through various electro-receptive devices, that are connected to the source by conducting circuits, and afterwards returns to the source.

The points of a source at which the electricity respectively leaves and enters it are called its poles; that point at which the current leaves the source being called its positive pole, and the point at which it enters the source, after it has passed through the receptive device, is called its negative pole.

The energy expended in operating an electric source is converted into electrical energy.

Electric sources are of a great variety of forms. They may be conveniently arranged into classes according to the character of the energy required to operate them.

Among electric sources by means of which mechanical energy or energy of motion is converted into electrical energy, are the frictional electric machine, the hydro-electric machine, the magneto-electric machine, and the dynamo-electric machine. Among those for converting the radiant energy of light or heat into electric energy, are the thermopile and various crystalline bodies like tourmaline. Among those for converting chemical potential energy into electric energy, are the voltaic cell and the charged storage battery.

Electro-receptive devices are means by which one or more of the effects produced by an electric discharge or current are obtained. They consist of various combinations of circuits in which various effects are produced, when an electric discharge or current is passed through them.

The poles of an electro-receptive device are the points where the current passes into and out of such device. The positive pole of an electro-receptive device is the pole connected with the positive terminal of the battery or electric source ; the negative pole of an electro-receptive device is the pole connected with the negative terminal of the battery or electric source. This usage is different from that adopted in the case of an electric source.

A great variety of electro-receptive devices have been devised; in all, however, electric energy is converted into some other phase of energy, such, for example, as chemical energy, heat energy, luminous energy, or mechanical energy.

In some forms of electro-receptive devices the electric energy is converted into more than a single form of energy, such, for example, as the electric lamp, where light, heat and magnetic energy are produced.

Among some of the more important forms of electro-receptive devices are electric motors, arc and incandescent lamps, plating baths, uncharged storage batteries, transformers, Leyden jars or condensers, electromagnets, electric bells, electric annunciators, and various telegraphic and telephonic apparatus.

It is important to remember that an electric source should not be regarded as producing electricity or electric currents. What it produces is a difference of electric potential; or, as it is commonly called, electromotive force.

When an electric source has produced a difference of potential or electromotive force at its terminals or poles, and these poles are connected by means of any conducting path, such difference of potential equalizes itself, and produces a discharge through such conducting path, or, in other words, causes an electric current to flow through it. The value of this current strength, in the case of steady currents, is directly proportional to the difference of potential or electromotive force, and inversely proportional to the resistance.

Differences of electric potential, or of electric level, may be regarded as similar to differences of liquid level. If a difference of liquid level exists between any two points in a vessel filled with liquid, and these two points are connected by an open tube, a current will be produced, and the liquid will flow through such tube from the higher to the lower level. The quantity of such flow will depend on the difference of level and the area of cross section of the tube.

Similarly, if a difference of electrical level or potential be obtained by means of an electric source, and any two points at different levels be connected by a conductor, an electric current will be produced which is assumed to flow from the higher to the lower level. The amount of such flow, in the case of steady currents, is directly proportional to the difference of level, and inversely proportional to the resistance. In all cases, the electricity produced by different sources as a result of difference of level, is assumed to flow from the higher to the lower level, or from the positive to the negative pole.

The electric current, or the rate of flow of electricity, between any two points, is conveniently expressed by the following formula:

$$C = \frac{E}{R}$$

in which C, equals the current strength; E, the electromotive force, and R, the resistance.

An electric circuit consists of an electric source or sources connected in a variety of ways with an electro-receptive device or devices by means of conducting paths.

Electric circuits are of a great variety of forms; in all, however, the current strength can be determined by means of the following formula, namely,

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In the series connection of electric sources the electromotive force of the source is equal to the sum of the electromotive forces of the separate sources.

In the multiple connection of sources, or electro-receptive devices, all the positive poles are connected to a single positive lead or conductor, and all the negative poles are similarly connected to a single negative lead or conductor. The resistance of such a circuit decreases with every source or device added in parallel.

In the multiple-series connection of sources or electro-receptive devices, a number of separate sources or devices are connected in separate groups in series, and these separate groups subsequently connected in parallel.

In the series-multiple connection of sources or electro-receptive devices these separate sources or devices are connected in separate groups in multiple, and these separate groups subsequently connected to one another in series.

The laws of magnetic attraction and repulsion may be expressed as follows, namely :

(1.) Like magnetic poles repel one another. Unlike magnetic poles attract one another.

(2.) The force of magnetic attraction or repulsion exerted by two magnetic poles is proportional to the product of the strength of the magnetism possessed by the two magnets, and under certain circumstances, is inversely proportional to the square of the distance between them.

Magnets are either natural or artificial, straight or curved, simple or compound.

All magnets possess two poles, a north and south pole. Anomalous magnets apparently possess more than two poles ; in such cases, however, a number of magnets are so placed together as to act apparently as a single magnet.

A magnet is surrounded by a region or atmosphere of influence called the magnetic field, which is traversed by what are called lines of magnetic force.

The presence of lines of magnetic force can be shown by placing a sheet of glass or paper over a magnet and sprinkling iron filings on its surface. On gently tapping the sheet, the iron filings are arranged in lines that follow generally the direction of the lines of magnetic force.

Magnets can be produced by stroking a magnetizable body by the poles of another magnet. The methods of magnetization by touch are mainly three, namely, single touch, separate touch and double touch.

The poles of a magnet are the points or places at which the lines of magnetic force pass out of or into the magnet. When a magnetizable body is brought into a magnetic field, the lines of force pass through it and the body becomes magnetized by induction. The points where the lines pass into the magnetized body become the south magnetic poles, and where they leave it, after having passed through it, the north magnetic poles.

When a body is magnetized by induction, the strength of the magnetization produced depends on the number of lines of force that pass through it. The polarity depends on the direction in which these lines of force pass through it, and the position of its magnetic poles, depends on the points where they enter and leave the body.

All lines of magnetic force form closed circuits. A part of their path lies within the mass of the magnet itself; the remainder of their path is completed through the medium which lies outside the magnet.

A complete magnetic circuit generally consists of three parts; namely:

(1.) The magnetic source or place where the lines of magnetic force are originated.

(2.) The magnetic circuit.

(3) The magneto-receptive devices.

In some cases, as in closed iron rings, the magnetic circuit is completed entirely through iron; in others such circuit is completed partly through iron and partly through air. Such circuits are called respectively, closed magnetic circuits and divided magnetic circuits.

Although it is not known what direction the lines of magnetic force actually take, yet for convenience it is assumed that they come out of the north pole of a magnet and enter the magnet at its south pole.

The portative power of a magnet, or its ability to hold a weight attached to its poles, is increased by the use of a soft iron armature.

A paramagnetic body, if cut in the form of a slender needle and suspended between the poles of a powerful electromagnet, will come to rest with its greatest length in the direction of the line of the poles. A diamagnetic body, when cut in the form of a slender needle and similarly placed, will come to rest with its least dimensions in the direction of the line of the poles.

Iron, steel, nickel, cobalt, chromium, cerium and manganese are paramagnetic substances. Bismuth, phosphorus, zinc and mercury are diamagnetic substances.

Ampère's theory of magnetism ascribes the production of magnetism to the presence of minute closed electric circuits located in the ultimate particles of matter.

When a substance is thoroughly magnetized, the circuits in all the particles are rendered parallel to one another; when demagnetized, this parallelism no longer exists.

Ampère's theory of magnetism explains coercive force as due to the resistance the circuits offer to being forced to assume parallelism.

Ampère showed that in the case of a cylindrical bar, when all these circuits were brought into parallelism, the effective magnetizing circuit could be correctly represented by a single spiral or coil of wire through which an electric current was passing. He called such a coil a solenoid, and showed, by numerous experiments, that the solenoid acquired magnetic polarity when traversed by an electric current.

Hughes' theory of magnetism assumes that the ultimate particles of matter are naturally magnetic; that in an unmagnetized bar these particles are arranged so as to neutralize each other, but that in a magnetized bar they are polarized or caused to point in the same direction. Hughes' theory closely resembles Ampère's. It differs, however, in assuming the particles to be originally magnetized without assigning any cause for such magnetization.

Ewing's theory of magnetism also assumes the ultimate particles of matter to be naturally magnetic. It does not assert, however, that any necessity exists for assuming that these particles resist any movements required to polarize them.

In 1838, at the suggestion of Alexander Von Humboldt, magnetic observations were made simultaneously in widely distant parts of the earth. By these observations it was established that magnetic disturbances occurring in one part of the earth were simultaneously accompanied by similar disturbances over all parts of the earth; or, in other words, that the earth acts as a huge magnet.

As in the case of an artificial magnet, the lines of magnetic force come out of the earth at its north magnetic pole, and, after passing through the air outside of the earth, enter it again at its south magnetic pole.

Calling the end of the needle that points toward the magnetic north of the earth the north magnetic pole of the needle, it follows that the south magnetic pole of the earth lies in the Northern Hemisphere.

The north pole of the needle points to the earth's geographical north in but few localities. Elsewhere it points either to the east or west of the true north. This variation from the earth's true north or south pole is called the magnetic declination.

The magnetic needle, when free to move in a vertical as well as a horizontal plane, comes to rest in a horizontal position in but few parts of the earth. In most localities either one or the other pole dips or inclines toward the earth's surface. This is called the inclination of the needle.

If the magnetic needle is slightly disturbed from its position of rest in the earth's field, it will make a number of oscillations, or to-and fro movements, before coming to rest. The number of such movements will be greater, the greater the intensity of the earth's magnetism at that particular place ; that is, the greater the number of lines of magnetic force that pass through a given unit of area of cross section.

The values of the magnetic declination, inclination and intensity at any place are called the magnetic elements of that place.

An isogonal map or chart is a chart on which the isogonal lines, or the lines passing through places whose magnetic declination is the same, are marked.

An isoclinal map or chart is a chart on which the isoclinal lines, or the lines passing through places which have the same inclination, are marked.

An isodynamic map or chart is a chart on which the isodynamic lines, or the lines passing through places whose magnetic intensity is the same, are marked.

The mariner's compass is an apparatus in which a magnetic needle is employed to determine north and south direction.

The cause of the earth's magnetism is unknown; it has been ascribed to electric currents circulating around the earth and to induction from the sun. Whatever may be its cause, a marked coincidence exists between the times of occurrence of magnetic storms and of these outbursts of solar energy called sun-spots.

The connection between an electric current and magnetism was first discovered by Oersted in 1819.

A conductor through which an electric current is flowing produces in the space outside it lines of magnetic force, which surround it as more or less concentric circles. Bodies brought into this magnetic field are affected as they would be in any other magnetic field; that is, they become magnetized by induction, have differences of potential set up in them when moved through the field so as to cut its lines of force, or are deflected from their position of rest as other magnets would be. In the magnetic field produced by an electric current the lines of magnetic force are assumed to take a direction the same as that which the hands of a clock would appear to take to an observer looking at such lines from below.

An electromagnet consists essentially of a core of soft iron on the outside of which is wrapped a coil of insulated wire. When an electric current is sent through this coil the core becomes powerfully magnetic with a polarity which depends not only on the direction in which the coil is wound, but also on the direction in which the current passes through it.

The magnetizing coils are called helices or solenoids. They are named according to the direction in which they are wound as right-handed and left-handed helices or solenoids.

The strength of an electromagnet is nearly proportional to the strength of the magnetizing current, provided the core is not saturated. It is also proportional to the number of ampère turns; that is, to the number of turns of wire in the coil through which one ampère passes.

Electromagnets assume a great variety of forms, such as horseshoe magnets, solenoidal magnets, cylindrical magnets, iron-clad magnets and zigzag magnets.

When an iron core is drawn into a hollow solenoid by its magnetic attraction, in order to insure a uniform pull the core is so shaped as to insure a greater mass at its central parts than at its ends. Cores so shaped are known technically as Krizik cores.

Electrostatics is that branch of electric science which treats of electric charges.

The laws of electrostatics may be expressed as follows :

(1.) Like charges repel, unlike charges attract each other.

(2.) The force of electrostatic attraction and repulsion exerted between two bodies is directly proportional to the product of the quantities of electricity possessed by the two bodies and inversely as the square of the distance between them.

Different media vary in their specific inductive capacity; that is, in their ability to permit electrostatic induction to take place between them.

As a rule the best insulators possess the highest specific inductive capacity.

An electric charge resides on the surface of an insulated conductor. Such a charge is said to be free when removed from the influence of neighboring charges, or is said to be bound when held in place by the opposite attraction of a charge on a neighboring body.

The Leyden jar is generally made for commercial use in a form known as the condenser. In such cases the metallic coatings are separated from one another by sheets of oiled silk or mica.

In the frictional electric machine an electric charge, developed by the friction of a rubber against a glass plate, is taken off the plate by the action of a series of points connected to an insulated conductor.

In the electrophorus a charge is obtained by the inductive action of a negatively excited resin disc on an insulated metallic plate placed near it. In order to obtain a free charge by induction the metal plate is first connected to the earth so as to part with a charge of the same name as that on the resin disc.

In the case of an electrostatic induction machine comparatively powerful charges are obtained on the principle of the electrophorus, means being provided for revolving such electrophori and automatically discharging them.

The Holtz and Wimshurst machines are good types of electrostatic induction machines.

Two of the older theories or hypotheses of electricity are the single-fluid hypothesis of Franklin and the double-fluid hypothesis of Du Fay.

There is always some free electricity in the atmosphere. This electricity is generally positive but readily changes to negative on the approach of a cloud or fog. It exists in greater amount in the upper regions of the air and varies at different times of the year or at different hours of the day or night.

The free electricity of the atmosphere is probably due to evaporation, to differences of temperature, chemical action, and, possibly, to a variety of other causes. It is, however, to the condensation of moisture or vapor that the high potential of the lightning flash is to be ascribed.

The lightning flash is caused by a discharge occurring between a charged cloud and the earth or between two neighboring clouds. The accompanying thunder is due to the disturbance of the air caused to some extent by the passage of the discharge through it, but mainly by the vacuum produced by the sudden condensation of the vapor formed by the passage of the discharge through rain-drops.

The following facts have been noticed concerning the geographical distribution of thunder storms:

(1.) They seldom occur in the polar regions.

(2.) They seldom occur in rainless districts.

(3.) They are most frequent and violent in the equatorial regions.

(4.) In regions beyond the tropics they occur for the greater part during those rainy seasons when the rain-fall comes from vapor which is condensed shortly after its formation.

There are five varieties of lightning:

(1.) Zigzag or forked lightning.

(2.) Sheet lightning.

(3.) Heat lightning.

(4.) Volcanic lightning.

(5.) Globular lightning.

A lightning rod protects a building to which it is attached either by actually discharging the charged cloud by means of a convective discharge, or by safely passing its discharge to the ground. A lightning rod to be effective must fulfill the following conditions:

(1.) Its area of cross section or conducting power must be sufficiently great.

(2.) It should either be continuous throughout, or, when jointed, the joints should be of small resistance.

(3.) Its upper extremity should terminate in a point or points of non corrodible material.

(4.) Its lower end should be thoroughly grounded.

(5.) It should project above the highest part of the building.

(6.) As to form, a flat rod is preferable to a cylindrical rod.

(7.) Iron is preferable to copper for lightning rods.

In order to protect instruments placed on telegraph, telephone or other lines employing bare conductors from the destructive effects of the lightning discharge, various forms of lightning arresters are employed.

Lightning arresters depend in principle on the fact that owing to the high inductance a disruptive discharge will take an alternative path to the ground through a small air space rather than through the coils of the instruments that are to be protected.

The aurora borealis occurs during the prevalence of an unusual quantity of free electricity in the atmosphere, and is believed to be due to the passage of electric discharges through rarefied air. This phenomenon occurs especially during the prevalence of sun-spots or during magnetic storms.

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